Assessment of Environmental Effects for water abstraction from Manuherikia River from the Falls Dam to the confluence with the Clutha/Mata Au

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Executive summary

The Manuherikia River enters the true left of the Clutha River at Alexandra. The observed natural 7-day MALF at Campground Flow Site (at Alexandra) is 0.912 m^3/s and the natural 7-day MALF is estimated at 3.9 m^3/s. We have determined that the Manuherikia River has a high degree of hydrological alteration due to the effects of water storage, augmentation and abstraction.

Water quality for the most part along the mainstem of the Manuherikia is good, meeting ORC's Schedule 15 water quality limits for nutrients at most sites throughout the river, with the only exception being DRP. Compared to the NPSFM (2020), NOF nutrient concentrations are in the A band for ammoniacal N and NNN while DRP is C band at sites from Ophir downstream.

The most recent trend analysis by NIWA[1] indicates that DRP concentrations are reducing which likely reflects the recent upgrades from overland flood irrigation to spray in the catchment over the last few years in anticipation of the water use efficiency requirements in the Regional Plan: Water and the NPSFM (2020) and its previous iterations.

At times of normal to low flow (less than median flow) microbial contamination is generally low in the Manuherikia River, meeting the Schedule 15 limit at all mainstem SoE sites except Ophir. The Ophir water quality site is immediately downstream of both Thomsons Creek[2] confluence and the Omakau Township wastewater discharge.

Throughout the catchment at times when people are reasonably expected to be recreating in the Manuherikia River[3] risk of illness from primary contact recreation in the Manuherikia is low. Our expectation is that with the recent upgrade of the Omakau wastewater discharge and anticipated changes to efficient spray irrigation that this risk will reduce further.

Monthly monitoring of periphyton cover and biomass at Blackstone Bridge, Ophir and Galloway, shows the invasive diatom Didymo dominated cover at Blackstone Hill on most occasions and that the biomass of periphyton was generally low to moderate at the Blackstone Hill site. The periphyton community at the Ophir and Galloway monitoring sites was generally dominated by thin light brown films (likely dominated by diatoms), although filamentous algae dominated both sites on occasion.

Overall using the NOF trophic state attribute as measured by chlorophyll-*a* biomass based on a monthly monitoring regime and acknowledging that there is not at least 3 years of data the sampling results so far indicate that all three mainstem sites in the Manuherikia are in the B-band for biomass.

Macroinvertebrate monitoring throughout the river under the existing flow regimes shows that depending on the metric used the sites monitored in the mainstem downstream of Falls Dam are classified from A to C Band under the NOF. Interestingly some of the lower MCI scores occur where water quality is known to be good which indicates that the invasive pest didymo is impacting some sites, particularly in the upper river at Loop Road and Blackstone.

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[1] See Table 8 of this report.

[2] Thomsons Creek has high *E.coli* levels based on SoE monitoring at SH85.

[3] Primary contact recreation is expected to occur when flows are less than 10 m^3/s and water temperatures are greater than 15^0C

Our analysis has also shown that abstraction is unlikely to affect periphyton flushing[4] in the lower Manuherikia. Based on observed flows at the Campground flow site, when a flushing flow does occur following rain it results in a mean flush flow of more than 80 m^3/s during the irrigation season.

The Manuherikia River between Falls Dam and Clutha confluence only has records of two species of indigenous fish; upland bully and Longfin eel that have been recorded more than a few times[5]. Upland bully are common and widespread while longfin eel are uncommon despite significant physical habitat for this species throughout the catchment. The Central Otago roundhead galaxias would naturally have been expected to inhabit the Manuherikia mainstem but has been extirpated by introduced trout.

Habitat modelling highlight that the scarcity of longfin eel in the Manuherikia catchment is due to a lack of recruitment past Roxburgh Dam and commercial harvest and not due to a lack of habitat due to low flows under the existing flow regime.

Under the existing flow regime, the mainstem of the Manuherikia is a regionally significant trout fishery with over 2,140 ± 830 angler days in the 2014/15 season[6]. The level of fishing effort puts the Manuherikia River under its existing flow regime in the top 50 most fished rivers in New Zealand[7]. Further to this two still water fisheries the Poolburn and Manorburn Reservoirs are also considered regionally significant trout fisheries by Otago Fish and Game[8] while Falls Dam is locally significant. These three still water fisheries would not exist under natural state conditions as these are storage reservoirs built specifically for irrigation.

The longitudinal pattern of flow and habitat requirements suggests that the adult trout fishery in the Manuherikia River benefits significantly from releases from Falls Dam and that without Falls Dam releasing flow for downstream taking adult trout habitat upstream of Omakau Area Irrigation intake (2001.702) would be reduced.

The risk to flows along the Manuherikia River if Falls Dam is emptied has also been investigated. With increasing minimum flow levels in the lower river, the risk of exhausting Falls Dam storage increases and the subsequent ecological risk across the river length increases also.

Fish passage has been assessed for all the large scheme intakes with none of the intakes expected to provide issues for migratory indigenous species. The OAIC intake weir likely impedes upstream trout passage but there is a self-sustaining population of large brown and rainbow trout upstream indicating passage is not causing significant issues.

Fish screens are recommended for all takes from the mainstem; our expectation is that given the species present 3mm mesh screens would be adequate. However, we would also suggest that sites for screening are best investigated on a case by case basis given the significant existing infrastructure already present.

To ensure the ecological values of the Manuherikia are maintained or improved a series of interventions have been recommended throughout the mainstem (Table 1).

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[4] We have used flows of 3x median flow or greater as periphyton flushing flows.
[5] Lamprey, Central Otago Roundhead galaxias and koaro have been recorded on rare occasions.
[6] Unwin, 2016. The national angler survey.
[7] Paragreen. N (2020). Presentation on behalf of Otago Fish and Game to the Manuherikia Reference Group.
[8] Section 5.2 of SPORTS FISH AND GAME MANAGEMENT PLAN FOR OTAGO FISH AND GAME REGION 2015-2025.

Table 1. Summary table of key mitigation measures to proposed to manage the ecological effects of abstraction along the mainstem of the Manuherikia River.

Site	**Residual flow**	**Fish screening**	**Minimum flow at Ophir**	**Minimum flow at Campground**	**Water sharing Recommended**
Falls Dam	0.720 m^3/s below dam	Not recommended	N/A	N/A	N/A
BIC Intake	Not required	Yes – 3mm mesh	Yes 0.820 m^3/s	Yes – 1.1 m^3/s	yes
OAIC intake	0.5 m^3/s below take	Yes – 3mm mesh	Yes 0.820 m^3/s	Yes – 1.1 m^3/s	yes
Private irrigation takes[9] upstream Ophir	Not required	Yes – 3mm mesh	Yes 0.820 m^3/s	Yes – 1.1 m^3/s	yes
MICS intake	Not required	Yes – 3mm mesh	No	Yes – 1.1 m^3/s	Yes
GIS intake	Not required[10]	Yes – 3mm mesh	No	Yes – 1.1 m^3/s	yes
Private takes downstream Ophir	Not required	Yes – 3mm mesh	No	Yes – 1.1 m^3/s	yes[11]

[9] Omakau town supply is in this reach.
[10] On the basis that the new intake design minimises bywash thereby leaving the majority of flow passing the point of take instream.
[11] These takes are very small (combined less than 10 l/s) and one take is below the Campground Flow Site. Excluding these from sharing will make little difference to flows

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1. Introduction

The Manuherikia River (catchment area: 3,033 km^2) is located in Central Otago. Its headwaters are in the Hawkdun and Saint Bathans Ranges and Dunstan Mountains, and it flows in a south-west direction, joining the Clutha River at the township of Alexandra.

There are currently 213 water takes in the Manuherikia catchment, with the sum of all consented maximum rates of take of 32 m^3/s although this figure is unlikely to reflect the actual rate of abstraction at any given time.

Several reservoirs have been constructed within the catchment, including Ida Burn Dam, Poolburn Reservoir, Manorburn Reservoir and Falls Dam. These storage reservoirs are operated by three irrigation companies The Falls Dam Company services four of the six irrigation schemes in the catchment.

The network of storage and races in the catchment has resulted in highly modified flows both by augmentation and abstraction. The most significant influence on the flow regime of the Manuherikia River itself is the augmentation of water from Falls Dam during the irrigation season in combination with the scheme off takes and their locations along the river.

This report attempts to summarise the different hydrological, ecological and water quality information available for the Manuherikia, ultimately recommending residual and minimum flows to manage the effects of taking to provide for the ecological values of the Manuherikia.

1.1. Scope of this assessment

The scope of this report is to provide an assessment of hydrology and aquatic ecology of the Manuherikia River from Falls Dam to the Clutha confluence (the length of river where consent applications are being made for), including consideration of potential mitigation options for managing the effects of abstraction (e.g. residual flows, minimum flows, fish screens etc.).

1.2. Available information

This assessment relies on the following information:

1. Certified flow records collected by Otago Regional Council (ORC) and NIWA from the Manuherikia Downstream of the Forks Flow Site, Manuherikia at Ophir and the Manuherikia at Campground.
2. Longitudinal gaugings by ORC and the Manuherikia Catchment Group (MCG).
3. Hydrological assessment of effects of different minimum flows on Falls Dam storage by WRM Ltd.
4. Synthetic flow records developed as part of the Manuherikia Goldsim Model.
5. Periphyton, macroinvertebrate and water quality data collected by ORC.
6. Habitat modelling completed by NIWA and Waterways Consulting on behalf of ORC.
7. Information from NIWA's Freshwater Fish Database.
8. Water quality reporting by ORC and NIWA.

2. Catchment Description

2.1. Climate

The climate of the Manuherikia catchment is typified by long, hot, dry summers and very cold, dry winters. The highest temperature recorded at Alexandra is 38.7°C and experiences an average of 7 days a year where maximum temperatures exceed 30°C, and an average of 35 days per year where maximum temperatures exceed 25°C (Macara 2015). Similarly, the highest temperature recorded at NIWA's Lauder research station is 35.0°C and it experiences an average of 3 days a year where maximum temperatures exceed 30°C, and an average of 33 days per year where maximum temperatures exceed 25°C (Macara 2015). In contrast, winters in the area are the coldest in the country. The lowest temperature recorded at Alexandra is -11.7°C and at Lauder is -19.7°C, and Alexandra experiences an average of 86 days and Lauder 104 days with the minimum temperature below 0°C (Macara 2015).

The mean annual rainfall at Alexandra is 363 mm and 439 mm at the Lauder Research Station with highest rainfall in December and January and lowest rainfall in late winter (Macara 2015). Rainfall increases from the valley floor (350-400 mm) to the top of the Dunstan Ranges (650 mm) (Figure 1).

2.2. Geology and geomorphology

The upper reaches of the Manuherikia River flow from the Hawkdun and St Bathans Ranges through a steep catchment, before flowing out onto flats below the Forks, where the gradient is markedly lower (Figure 2). The western tributaries of the Manuherikia River (Chatto, Thomsons, Lauder, Dunstan) flow out of Dunstan Mountains, with the upper reaches flowing through steep, bedrock-dominated channels before flowing out onto flats below the forks, where the gradient is markedly lower (Figure 2). The basement rocks of the ranges are schist, while the valley floors are dominated by quaternary outwash gravels of various ages along with deposits of lacusturine clay, silt and oil shale with minor lignite seams, quartz sand and conglomerate.

2.3. Catchment landuse

The majority of the Manuherikia catchment consists of low producing grassland (122,715 ha; 40%), tall tussock (83,349 ha; 27%), and high producing grassland (63,637 ha; 21%) (Figure 3). There are significant areas of bare gravel (such as scree slopes; 8,708 ha; 3%) and alpine grass/herbfield (4,217 ha; 1%) in the upper catchment (Figure 3). Scrub (including gorse, broom, matagouri, grey scrub, manuka/kanuka, mixed exotic shrubland and sub-alpine shrublands) collectively covered 3% of the catchment (9,896 ha).

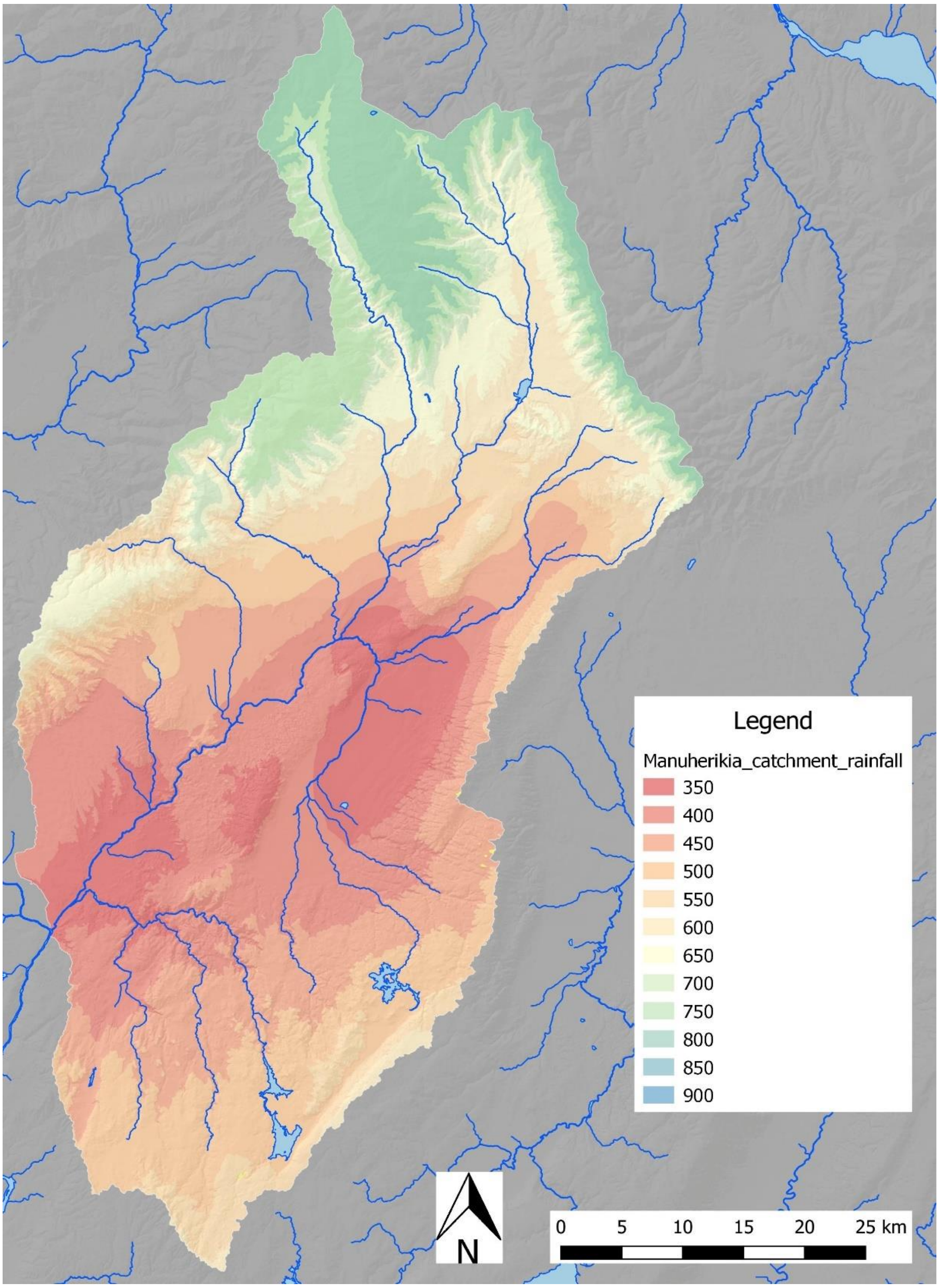

Figure 1. Mean annual rainfall (mm) of the Manuherikia catchment based on Grow Otago (courtesy of Otago Regional Council).

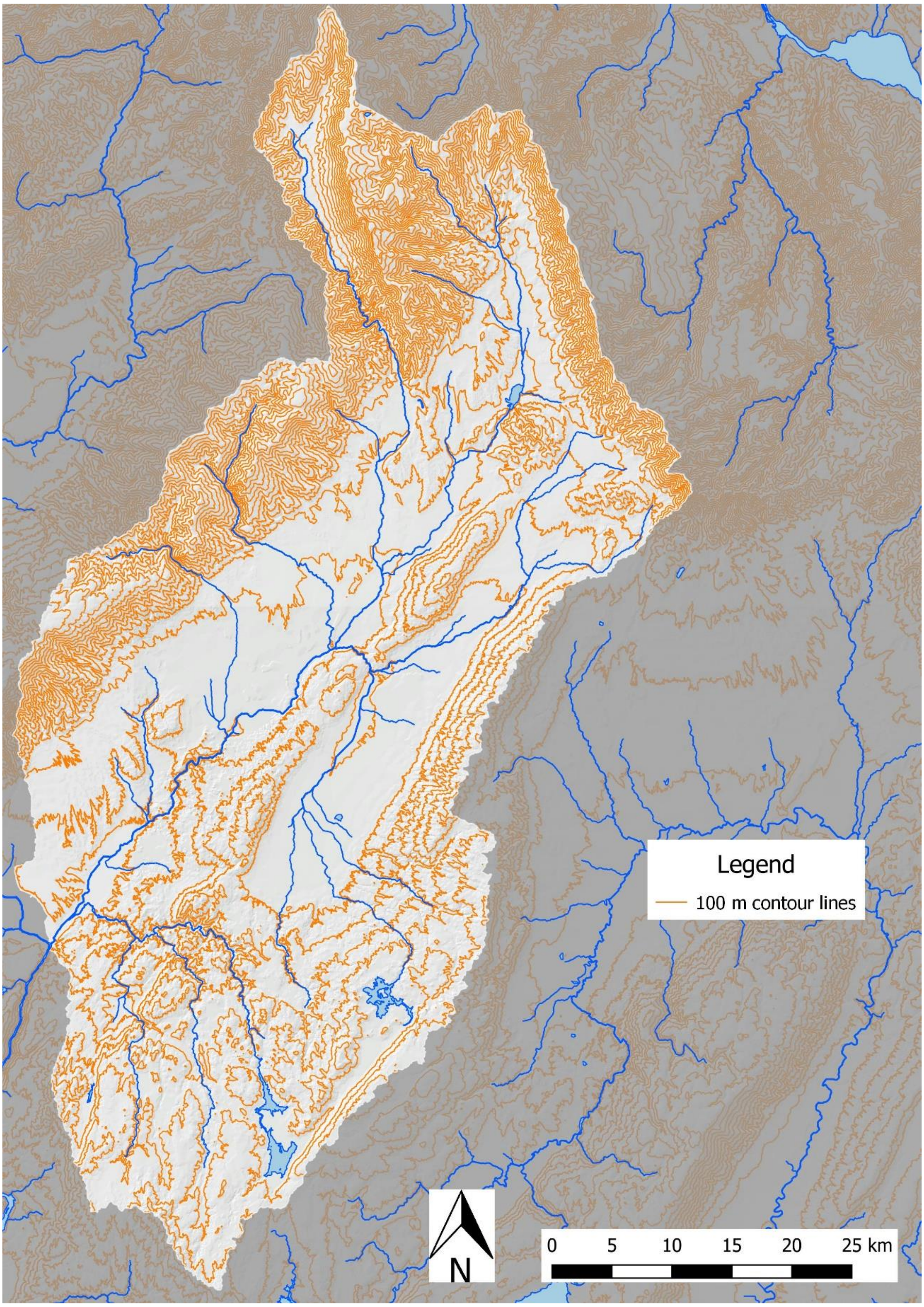

Figure 2. Topography of the Manuherikia catchment based on 1:250,000 scale contours. Contour spacing is 100 m.

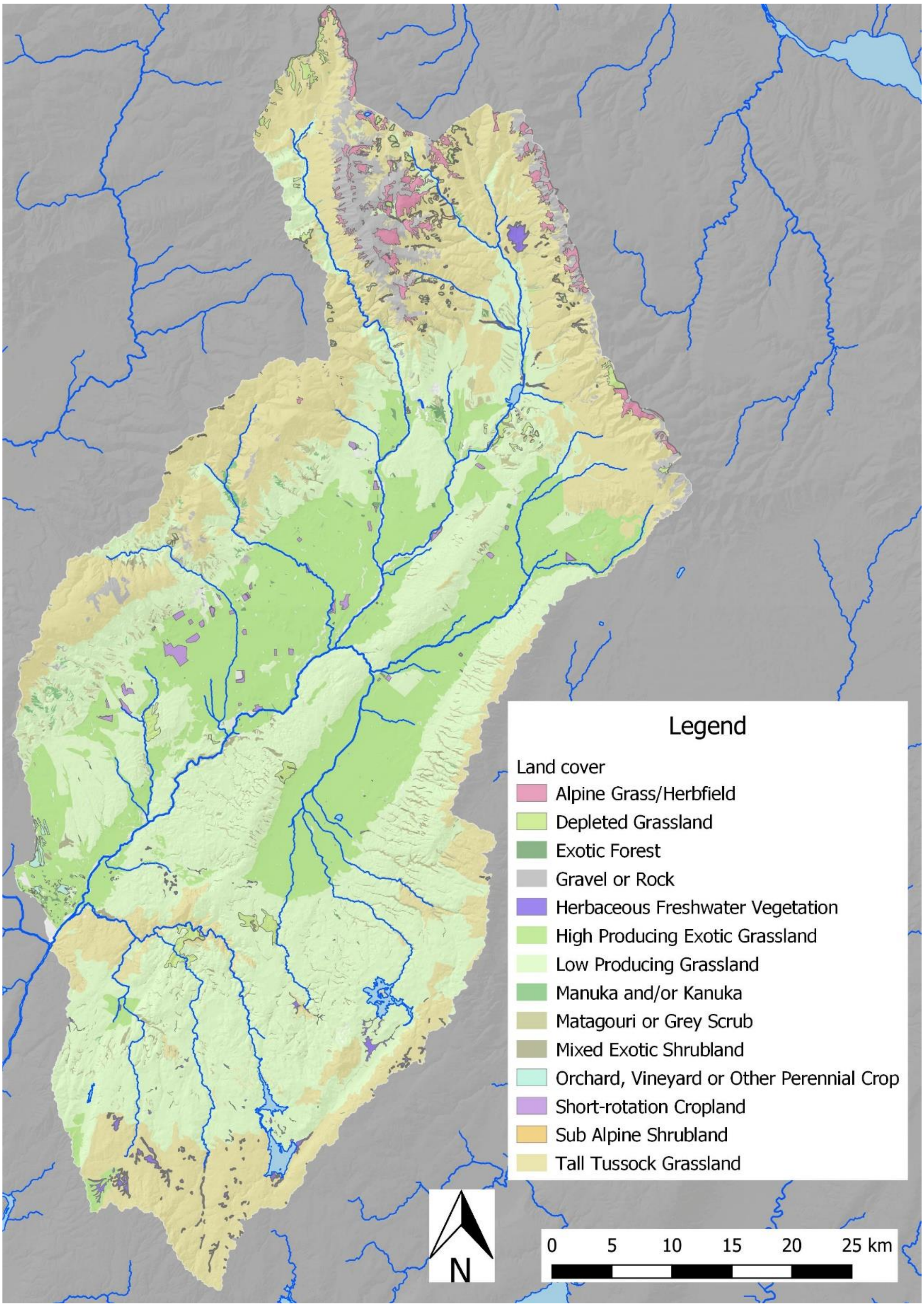

Figure 3. Land cover of the Manuherikia catchment based on the Land Cover Database (LCDB, version 4.1)

3. Hydrology

ORC and NIWA have three long-term flow sites on the Manuherikia River, Downstream of the Forks which is in the headwaters (upstream of Falls Dam), Manuherikia at Ophir which is in the mid reaches and Manuherikia at Campground which is near the confluence with the Clutha River (Figure 4). Two recent flow sites have been added by ORC, one below Falls Dam and the other immediately above the Chatto Creek confluence, while the Manuherikia Catchment Group (MCG) have also added a site below the Dunstan Creek confluence (Figure 4).

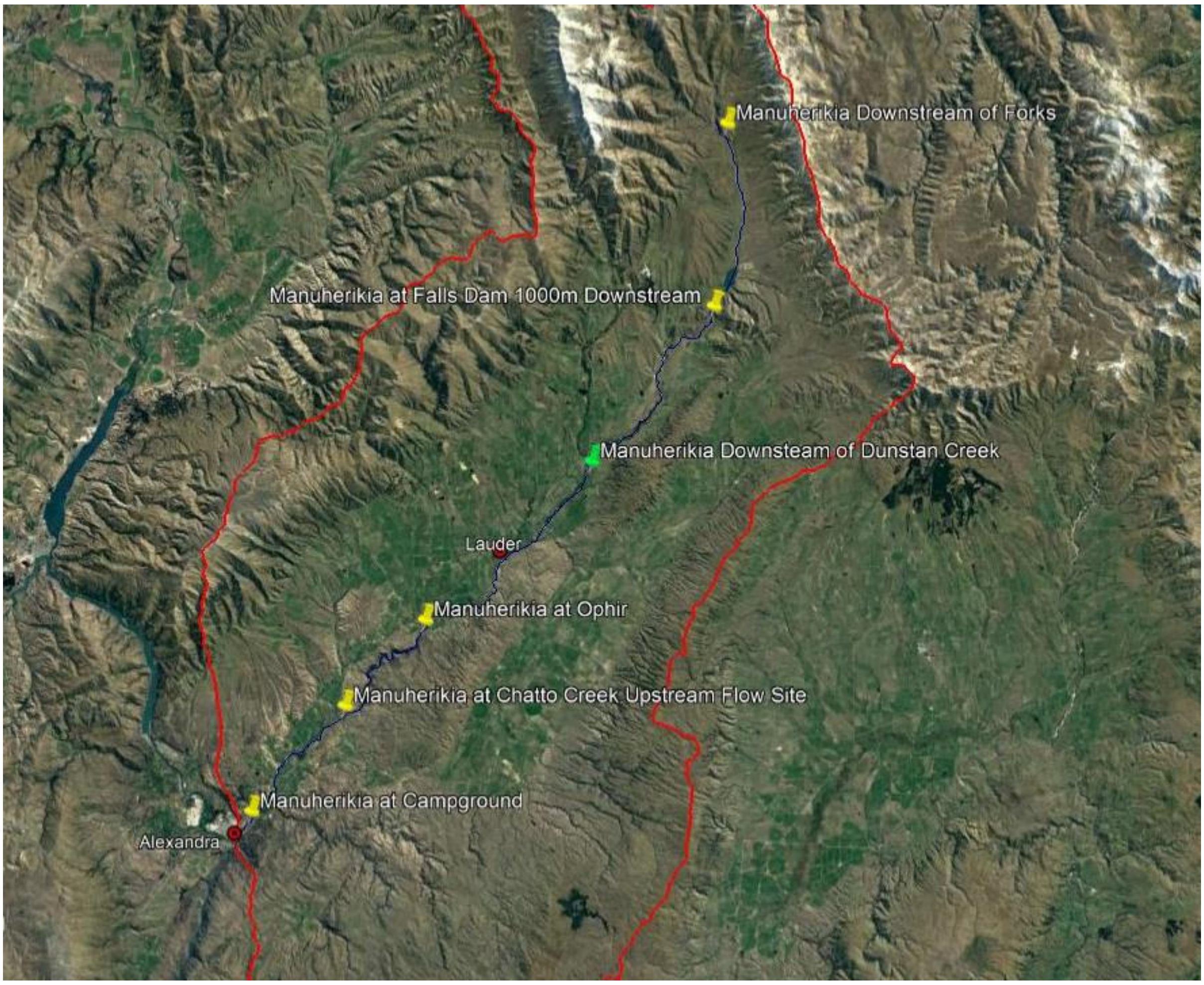

Figure 4. Flows Sites along the Manuherikia mainstem, yellow pins are ORC and NIWA sites and the green pin is a Manuherikia Catchment Group site.

All mainstem flow sites in the Manuherikia are affected by abstraction and several are affected by storage impoundments[12]. At the time of writing this report there is no naturalised flow record for the Manuherikia River, as a result this assessment relies on observed flows, and naturalised estimates of the 7-day MALF[13]. We are also aware the ORC are awaiting a hydrological model that can be used to assess different flow management scenarios and there effects on river and tributary flows, Falls Dam storage and irrigation reliability. Unfortunately, this model was not completed prior to consent lodgement deadlines. However, we envisage that this model will help assess the proposal outlined in

[12] Only ORC's Downstream Forks Flow Site is not affected by storage.

[13] Natural 7-day MALF estimates have previously been made by ORC and NIWA in Olsen *et al.* (2017).

this document and if it brings forward new information that supports adjustment to our recommendation then we will work with ORC to address this.

Finally, to understand the hydrology of the Manuherikia River it is important to understand the take locations for the four irrigation schemes, including their rates of take and the how Falls Dam is operated, this is addressed below.

3.1. Manuherikia River Mainstem Takes

There are four large scheme takes and six private takes from the Manuherikia between Falls Dam and Alexandra (Figure 5).

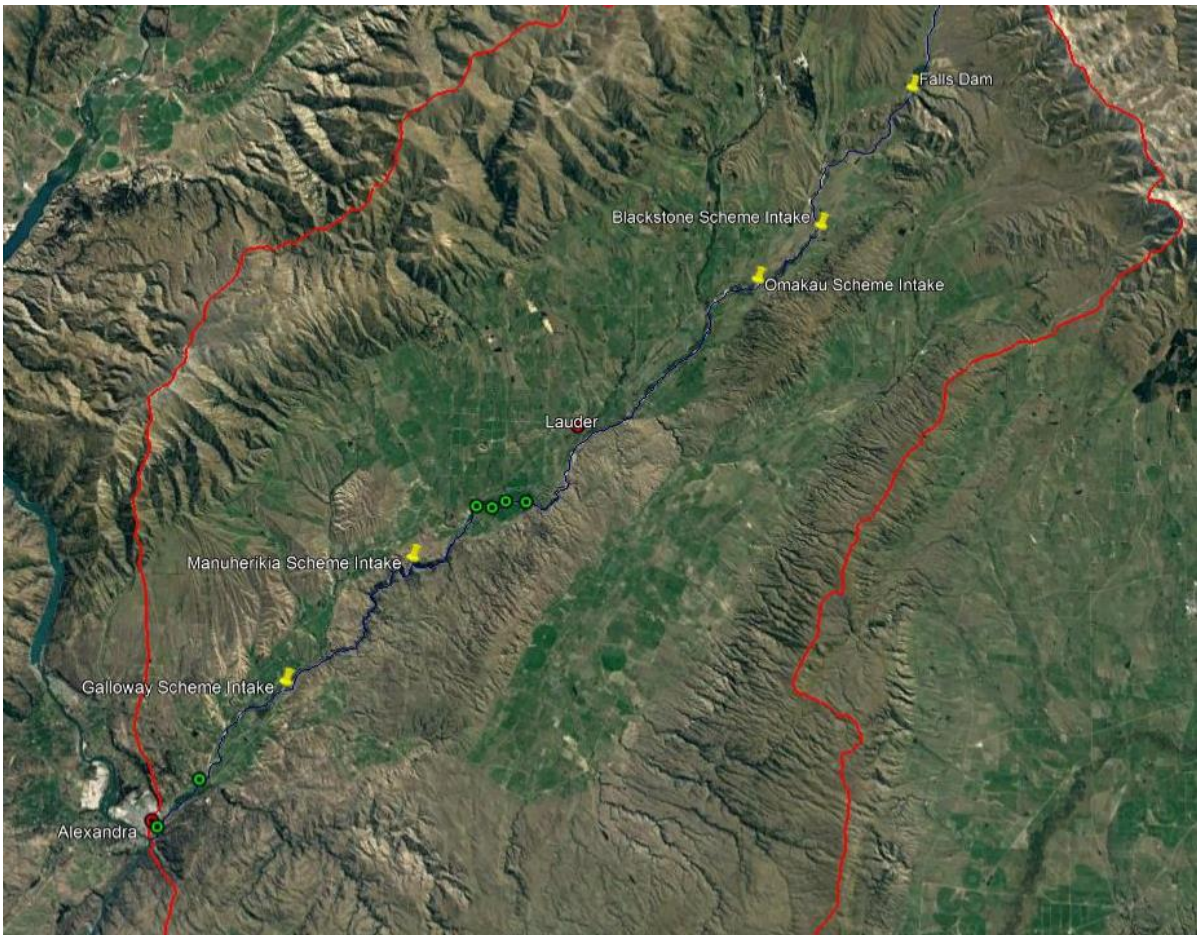

Figure 5. Mainstem primary water take locations from the Manuherikia River, yellow pins are scheme takes and green dots are private takes.

Table 2 provides the existing consented rates of take for the 10 primary takes from the Manuherikia mainstem and it highlights the smallest scheme take (0.404 m^3/s) is larger than the six private takes combined (0.311 m^3/s).

Table 2. Consented maximum rates of take and actual use maximum rates of take for mainstem primary takes from the Manuherikia River.

Take	Consented Maximum Rate of Take (m^3/s)	Observed Actual Maximum Daily Average Rate of Take between 2014 and 2020 during the irrigation season (m^3/s)
Blackstone Irrigation Company	0.404	0.404
Omakau Area Irrigation Company	1.981	1.981
2002.187	0.139	0.086
99477	0.083	0.083
2010.191.V1	0.056	0.056
99169	0.035	0.008
Manuherikia Irrigation Company Society	2.830	2.031
Galloway Irrigation Society	0.425	0.292
RM11.049.01	0.050	0.007
RM20.197.01	0.004	0.001
Total mainstem take	5.951	4.949

Table 2 illustrates that although the sum of consented maximum rates of take is 5.951 m^3/s, the sum of maximum daily average rates of take based on actual use is less at 4.949 m^3/s. Further analysis shows that the maximum combined rate of abstraction for all mainstem takes on any given day during the irrigation season between July 2014 and June 2020 was 4.613 m^3/s. This highlights the need to understand actual use for assessing the effects of taking and not simply relying on consented maximum take rates.

3.1.1. Blackstone Irrigation Company

Blackstone Irrigation Company (BIC) operates the smallest scheme take (consented to take 0.404 m^3/s) from the Manuherikia River at Blackstone Hill which relies on a gravel bund to guide flows to the true left bank of the river and the intake (Figure 6).

Figure 6. BIC intake

3.1.2. Omakau Area Irrigation Company

Omakau Area Irrigation Company (OAIC) operates a large take (consented to take 1.981 m^3/s) from the Manuherikia River above Becks which relies on a concrete weir diverting flows to the true left bank of the river and the gated intake (Figure 7).

Figure 7. The OAIC intake.

3.1.3. Manuherikia Irrigation Co-operative Society

Manuherikia Irrigation Co-operative Society (MICS) operates a large take (consented to take 2.830 m^3/s) from the Manuherikia River downstream of Ophir which relies on a rock wall guiding flows to the true right bank of the river and the intake (Figure 8).

Figure 8. Looking downstream at the MICS intake

3.1.4. Galloway Irrigation Society

Galloway Irrigation Society (GIS) operates a moderate take (consented to take 0.425 m^3/s) from the Manuherikia River above Galloway which relies on a gravel wing wall that guides flow to the true left bank of the river and the race intake (Figure 9).

Figure 9. Looking downstream at the GIS intake.

3.2. Falls Dam Operation

Falls Dam is operated primarily as a storage reservoir to maintain irrigation reliability for the four scheme takes along the Manuherikia River. Flows are managed by the dam manager who releases only the water needed to meet irrigation demand and maintain a voluntary target flow of 0.9 m^3/s[14] at ORC Campground Flow Site near Alexandra and the regulatory minimum flow of 0.820 m^3/s at Ophir.

As flow contributions to the Manuherikia River from the wider catchment below Falls Dam recede, the flows released from Falls Dam are increased (up to ~4m^3/s) in response to meet irrigation demand and deliver the target flow at Campground.

If the water level in the dam recedes and inflows remain low Falls Dam Company will initiate a restriction to maintain storage for as long as possible into the season, this is usually done by reducing taking throughout the catchment by a nominated amount and reducing the amount of water released from the dam (Appendix 1).

Figure 10 illustrates that during peak demand it is not unusual for Falls Dam to be releasing more than 1 m^3/s in excess of what is coming into Falls Dam meaning that when flows are low more than 40% of the combined take by the schemes can be coming from stored water.

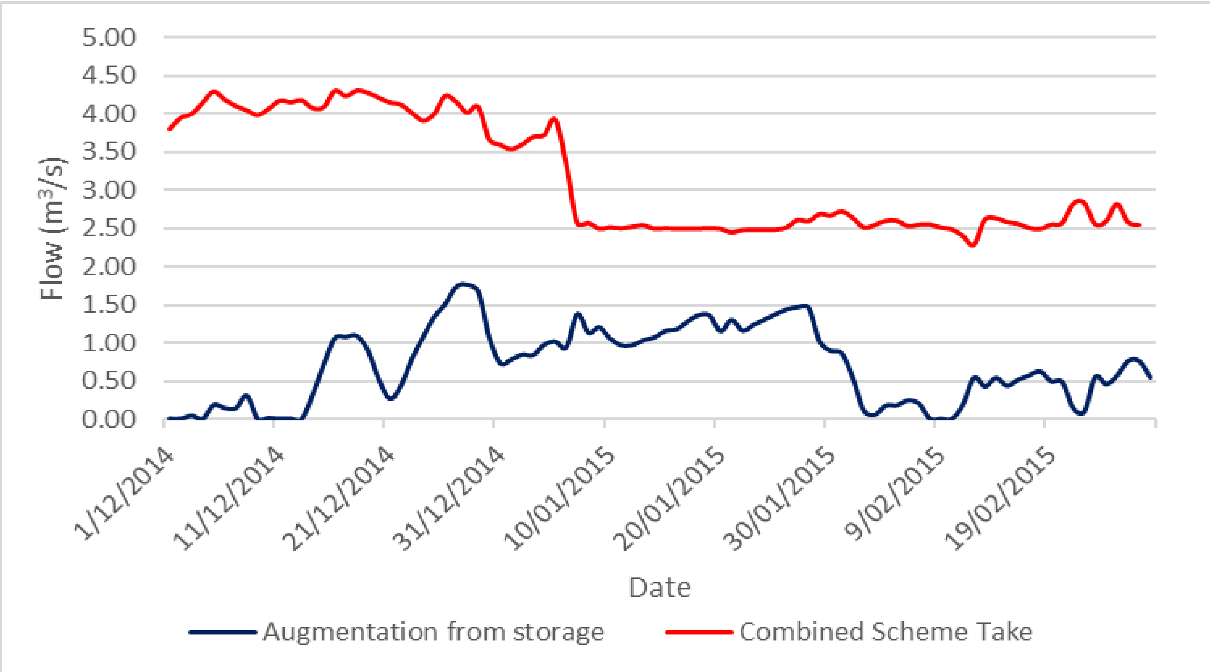

Figure 10. Additional flow over and above the observed inflow that was released from Falls Dam during the summer of 2014/15 compared to the combined daily average take by the four schemes for the same period (from early January the schemes were on voluntary restrictions).

[14] The catchment voluntarily works together and makes its best endeavours to maintain at least 900 l/s at Campground Flow Site. On occasion and with agreement from ORC a flow of 600 l/s has been maintained at Campground Flow Site to prevent Falls Dam emptying which would result in depleted flows along the length of the river relative to flows when the dam is releasing.

3.3. Hydrological Statistics

There are three flow sites on the mainstem of Manuherikia River that have more than 10 years of record, these are:

1. Observed flows at Manuherikia Downstream of the Forks Flows Site.
2. Observed flows at Ophir.
3. Observed flows at Campground.

Table 3 provides observed flow statistics for the Manuherikia River at the three sites with more than 10 years of flow record.

Table 3. Observed flow statistics based on daily average flows for the Manuherikia River mainstem.

Site	Record Length	Catchment Area Above Flow Site (km^2)	Lowest Daily Flow (m^3/s)	1-Day MALF (m^3/s)	7-Day MALF (m^3/s)	Median (m^3/s)	Mean (m^3/s)	Max (m^3/s)
Manuherikia downstream of Forks[15]	1975-Present (with gaps)[16]	176	0.510	0.821	0.880	2.395	3.096	68.928
Manuherikia at Ophir[17]	1971 - Present	2,108	0.457	1.864	2.152	9.264	13.925	497.731
Manuherikia at Campground[17]	2008 - Present	3,010	0.406	0.698	0.911	11.777	16.215	465.457

3.4. Flow Exceedance

Figure 11 below provides flow exceedance curves for flows of less than 16 m^3/s[18] for flows at the downstream of forks flow site (above Falls Dam), Manuherikia at Ophir (mid catchment) and Manuherikia at Campground (lower catchment).

[15] Above Falls Dam
[16] Significant gaps are for 1994 – 1999, 2004 – 2008 and 2010 – 2016.
[17] Below Falls Dam
[18] Observed mean flow at Campground flow site is 16m^3/s.

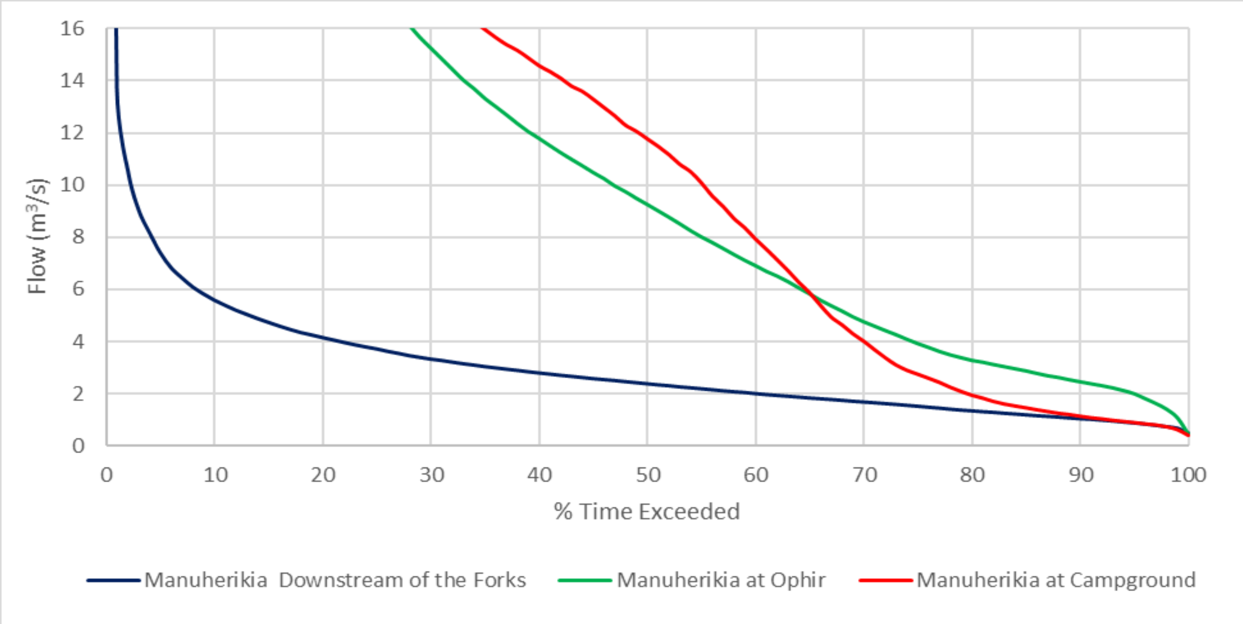

Figure 11. Flow exceedance curves for the three mainstem Manuherikia Flow Sites relied on in this report.

Figure 11 shows that ~35% of the time flows observed at Campground are lower than at Ophir despite the catchment area being 902 km^2 greater at Campground. This highlights the greatest hydrological effect from abstraction occurs downstream of Ophir and that releases from Falls Dam somewhat mitigate hydrological effects observed at Ophir.

3.5. Longitudinal Flows

Between December 2017 and January 2020, ORC and the Manuherikia Catchment Group have carried out several sets of flow gaugings in the lower Manuherikia River from the Ophir Gorge above the Chatto Creek confluence to the Campground flow site (Figure 12). These gaugings were to try to understand if there were any consistent groundwater gains or losses in this reach.

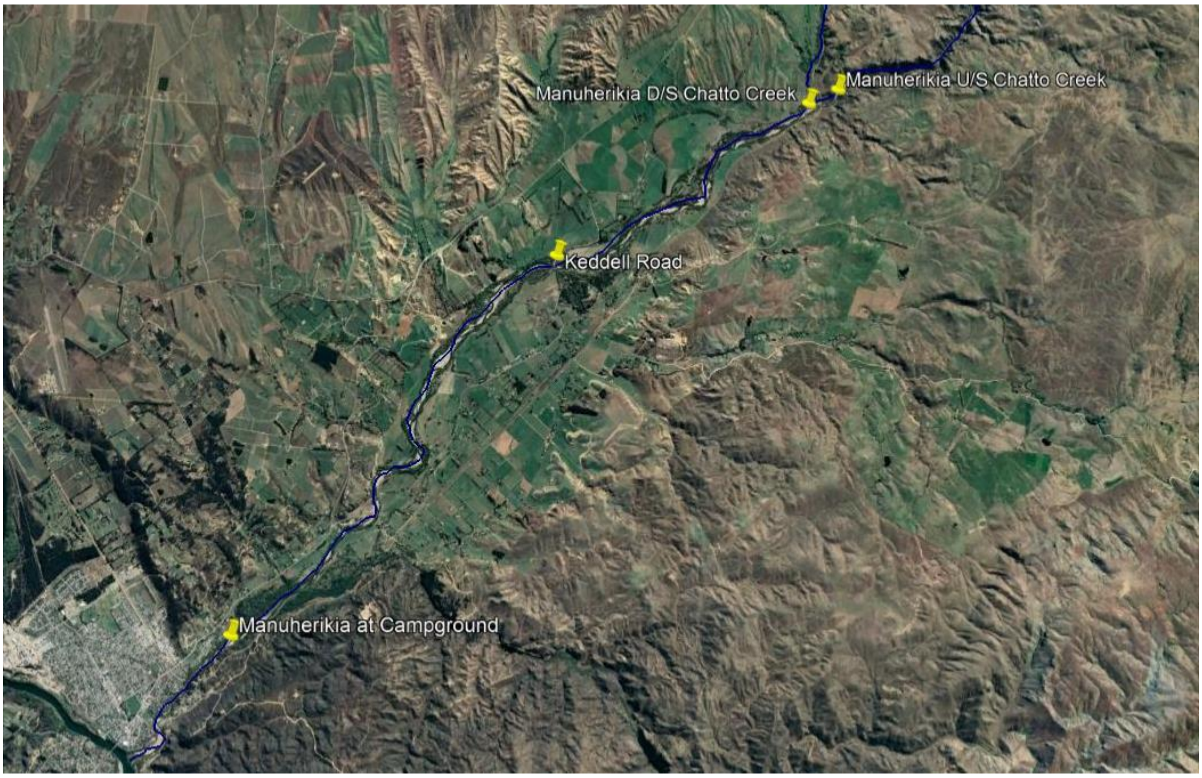

Figure 12. Locations of common NIWA and ORC gaugings sites on the lower Manuherikia between December 2017 and February 2018.

Below we present the gaugings that were carried out when Campground flows were less than 1.5 m^3/s for the reach from the bottom of Ophir Gorge to Campground flow site (Table 4). We have used flows of less than 1.5 m^3/s at Campground because we were specifically interested in groundwater gains or losses across the reach and our observation is that at higher flows (>2 m^3/s) there can be surface inflows that would make it hard to decern the difference between groundwater and surface water gains.

Table 4. NIWA and ORC gaugings of the lower Manuherikia from December 2017 to January 2020 when flows were less than 2.0 m^3/s at Campground flow site.

Date	Manuherikia at Ophir Gorge below the MCIS intake (m^3/s)	Chatto Creek U/S of Confluence (m^3/s)	Manuherikia D/S of Chatto Creek Confluence (m^3/s)	Galloway Irrigation Company Daily Average Take (m^3/s)	Manuherikia at Keddell Road (m^3/s)	Manuherikia at Campground Daily Average Flow (m^3/s)
20/12/2017	0.798	0.182	0.980	0.255	0.726	0.802
03/01/2018	0.876	0.122	0.998	0.154	0.925	0.917
17/01/2018	1.017	0.112	1.129	0.147	1.075	1.055
31/01/2018	0.715	0.069	0.784	0.105	0.576	0.676
19/02/2018	0.675	0.235	0.910	0	0.997	1.082
07/02/2019	0.416	0.421	0.837	0.154	0.754	0.917
11/02/2019	0.353	0.373	0.726	0.267	0.489	0.676
17/01/2020	0.781	0.370	1.151	0.256	1.003	1.312
23/01/2020	0.624	0.324	0.948	0.250	0.764	0.917

Figure 13 below provides the longitudinal flow profiles between Ophir and the Clutha confluence for the gaugings shown in Table 4 with the addition of flows at Ophir on the day and the MICS take.

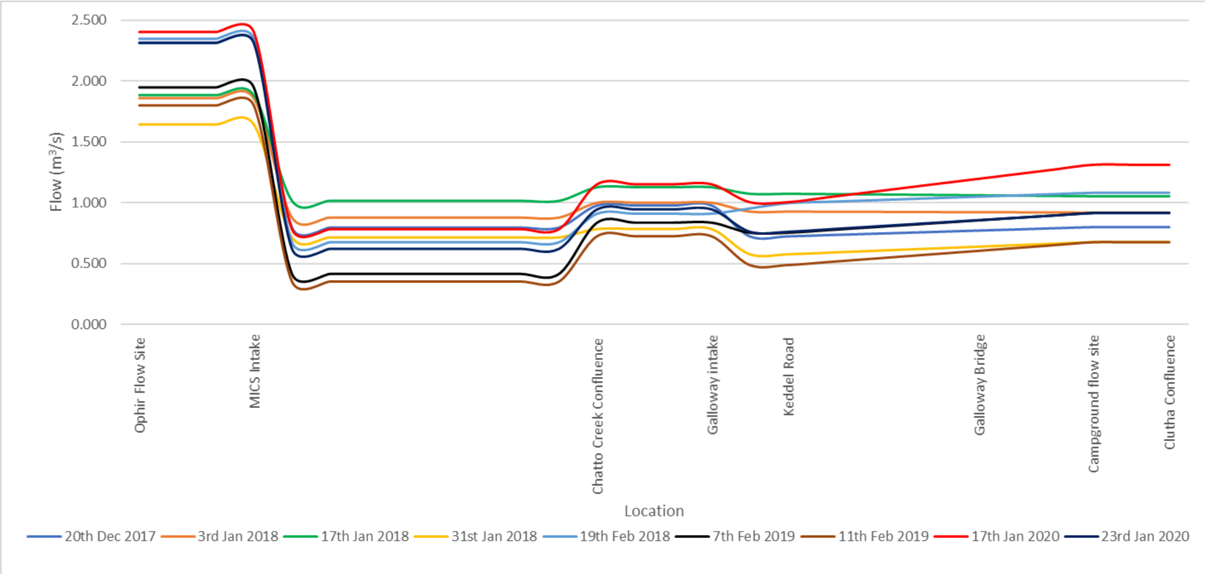

Figure 13. Longitudinal Flows in the Lower Manuherikia when Campground is less than 1.5 m^3/s based on Table 4.

Once the GIS take is accounted for the Keddell Road gaugings results generally fall within 10%[19] of the flows observed immediately below the Chatto Creek confluence. This indicates that the reach from below the Chatto Creek confluence to Keddell Road is a neutral reach with possibly a slight gain[20] (Table 4 and Figure 13). From Keddell Road to the Campground flow recorder the average gain is 0.121 m^3/s, ranging from a 0.008 m^3/s loss to a 0.309 m^3/s gain (Table 4 and Figure 13).

With the prevalence of overland irrigation between the Chatto Creek confluence and the Campground flow site on both sides of the river we could not determine what proportion of the gains were from irrigation returns, especially given the variability in gain. As a result of these gaugings we have attributed a gain in our status quo or observed flow profiles below of 0.150 m^3/s but reduced this to 0.050 m^3/s for our natural flow profiles as irrigation returns would not occur naturally. With conversion to spray irrigation in the future we would expect that this gain would reduce, so have only attributed a 0.050 m^3/s gain in any future scenarios in this report.

Below we present, as best as we can, natural flows longitudinally along the Manuherikia River relative to those observed, we have used a natural 7-day MALF flow of 3.9 m^3/s at Campground[21] and a natural low flow the equivalent of 2.125 m^3/s at Campground.

[19] Ranging from 15% less to 12% more with the difference more often than not showing slightly more flow.
[20] This conclusion is across the reach gauged, it does not preclude there being a losing reach between Chatto Creek and Keddell Road for example.
[21] Olsen *et al.* (2017). Management flows for aquatic ecosystems in the Manuherikia River and Dunstan Creek. Otago Regional Council, Dunedin. 78 p. plus appendices.

As explained above, during times of low flow releases from Falls Dam are managed to provide for abstraction at all downstream takes while aiming to maintain 0.9 m^3/s at the Campground flow site[22]. This can mean that flows from Falls Dam are significantly higher than inflows or flows that would naturally occur downstream to the OAIC intake[23]. The reach of the Manuherikia River from Dunstan Creek to the MICS intake some 25 km downstream observed flows and flows expected under natural conditions are similar. From the MICS intake to the confluence, observed flows significantly depart from what would be expected naturally (Figure 14).

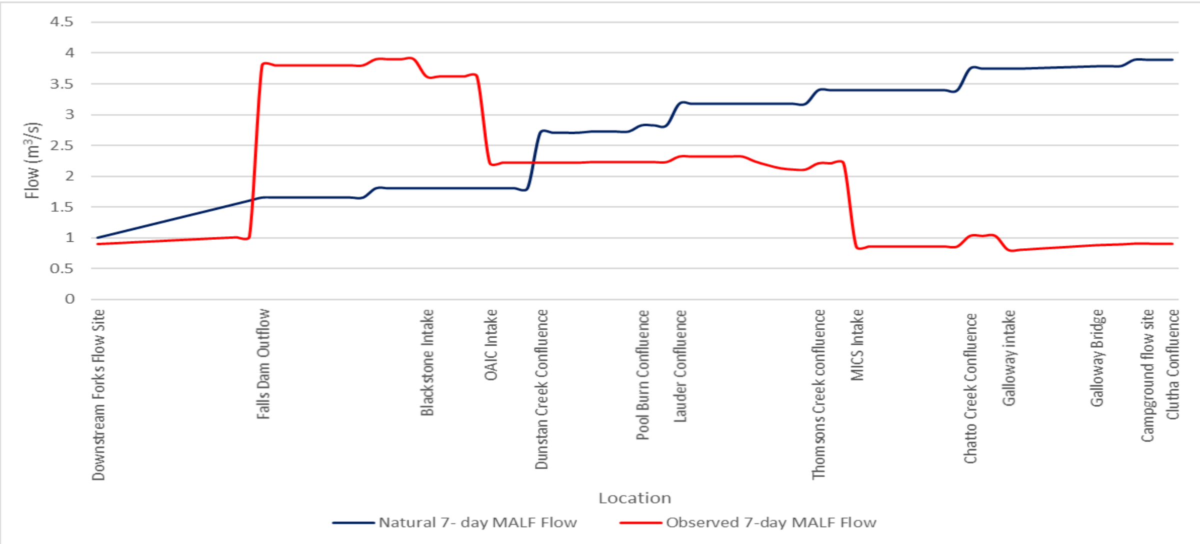

Figure 14. Longitudinal Flows expected under the natural 7-day MALF and observed 7-day MALF at the Downstream Forks, Ophir and Campground flow sites. It is 83 km from the Forks Flow Site to the Clutha Confluence.

During more severe low flows than the 7-day MALF, the difference between natural and observed flows from Dunstan Creek to MICS intake are less pronounced, but again the greatest departure in flows between natural and observed flows is from the MICS intake downstream (Figure 15).

[22] Except in 2014/15 season where Falls Dam was at risk of running out early and there was an agreement with ORC to reduce Campground to 0.6 m^3/s.

[23] Blackstone Irrigation Company takes water immediately upstream of OAIC.

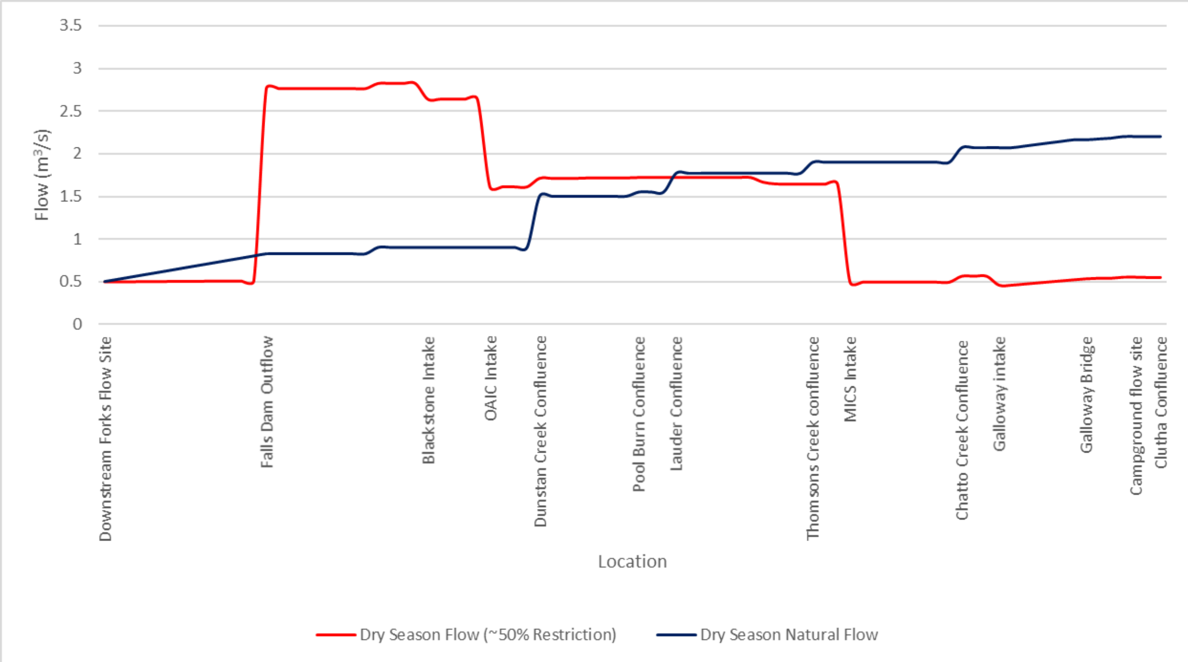

Figure 15. Comparing natural and observed longitudinal flows under a low flow event comparable to January 2018 at the Downstream Forks, Ophir and Campground flow sites. It is 83 Km's from the Forks Flow Site to the Clutha Confluence.

Both Figure 14 and Figure 15 highlight the significant alteration in hydrology that has occurred in the Manuherikia since Falls Dam was built. From Falls Dam to the Clutha confluence the longitudinal flow pattern has effectively been reversed when compared to what would occur naturally during low flow periods (Figure 14 and Figure 15). Based on the flow exceedance curves presented in Figure 11 this change in longitudinal pattern occurs about a third of the time.

4. Accrual Time

Accrual time or time between floods is a significant driver of periphyton biomass[24], simply the longer the time of accrual the higher the risk of significant periphyton biomass accumulating.

In order to investigate the effect of abstraction on accrual time we have determined the average and maximum number of days between flushing flows[25] at Falls Dam based on modelled natural flows (no dam) for the period of record 1973 – 2020 compared to observed flows at ORC's Campground flow site in the lower Manuherikia. Ideally, we would have compared natural to observed flows at Campground but at the time of writing this report there is no naturalised flow record for the Campground site.

Before calculating the average number of days of accrual we removed accrual periods of less than 10 days, this is because often there is a flush quickly followed by another flush a few days later. In reality these are part of the same event or they are so close together that periphyton hasn't begun to grow.

[24] Biggs, B.F.J. (2000). New Zealand periphyton guidelines: Detecting, Monitoring and Managing Enrichment of Streams. Prepared for the Ministry for the Environment.

[25] A flushing flow of 3X the natural median has been used, this is a flow of 12.645 m^3/s.

Table 5 below provides a comparison of accrual times between modelled natural flows at Falls Dam and observed flows at Campground.

Table 5. Mean and maximum accrual times at Falls Dams based on natural flows (1973 - 2020) and observed flows for the Manuherikia at Campground (2008 – 2019) and a flushing flow of 36 m^3/s (3x median).

	Mean Number of Accrual Days	Maximum Number of Accrual Days
Natural Flow Falls Dam	84	435
Observed at Campground	91	360

Our analysis found that, on average, there is 91 days between flushing events at the Campground flow site, with the longest number of days between flushes being 360 days over the period 2008 -2019. This analysis suggests that flushing flows of 3x median or higher occur at an interval comparable to what would be expected naturally based on the naturalised reference flows at Falls Dam (Table 5).

For the full record at Campground flow site, the mean of the peak daily flow for each discrete flush event more than 10 days apart at Campground is 114 m^3/s. Further to this during the irrigation season (Oct – April) the mean peak daily flow for each discrete flush event more than 10 days apart at Campground is 86 m^3/s. Our expectation is that current levels of abstraction are unlikely to significantly alter flushing events at Campground flow site, this is because the majority of takes are run of the river and when demand is reduced or low they are either off or taking a minimal amount as would be expected when flows at Campground are above 80 m^3/s.

5. Current Physical State

5.1. Water quality

A review of water quality in the Manuherikia catchment conducted by NIWA for the Otago Regional Council (Hudson & Shelley 2019) included several sites in the mainstem of the Manuherikia River: Manuherikia at Loop Road, Manuherikia at Blackstone Hill, Manuherikia at Omakau, Manuherikia at Ophir, Manuherikia u/s Chatto and Manuherikia at Galloway (Figure 16).

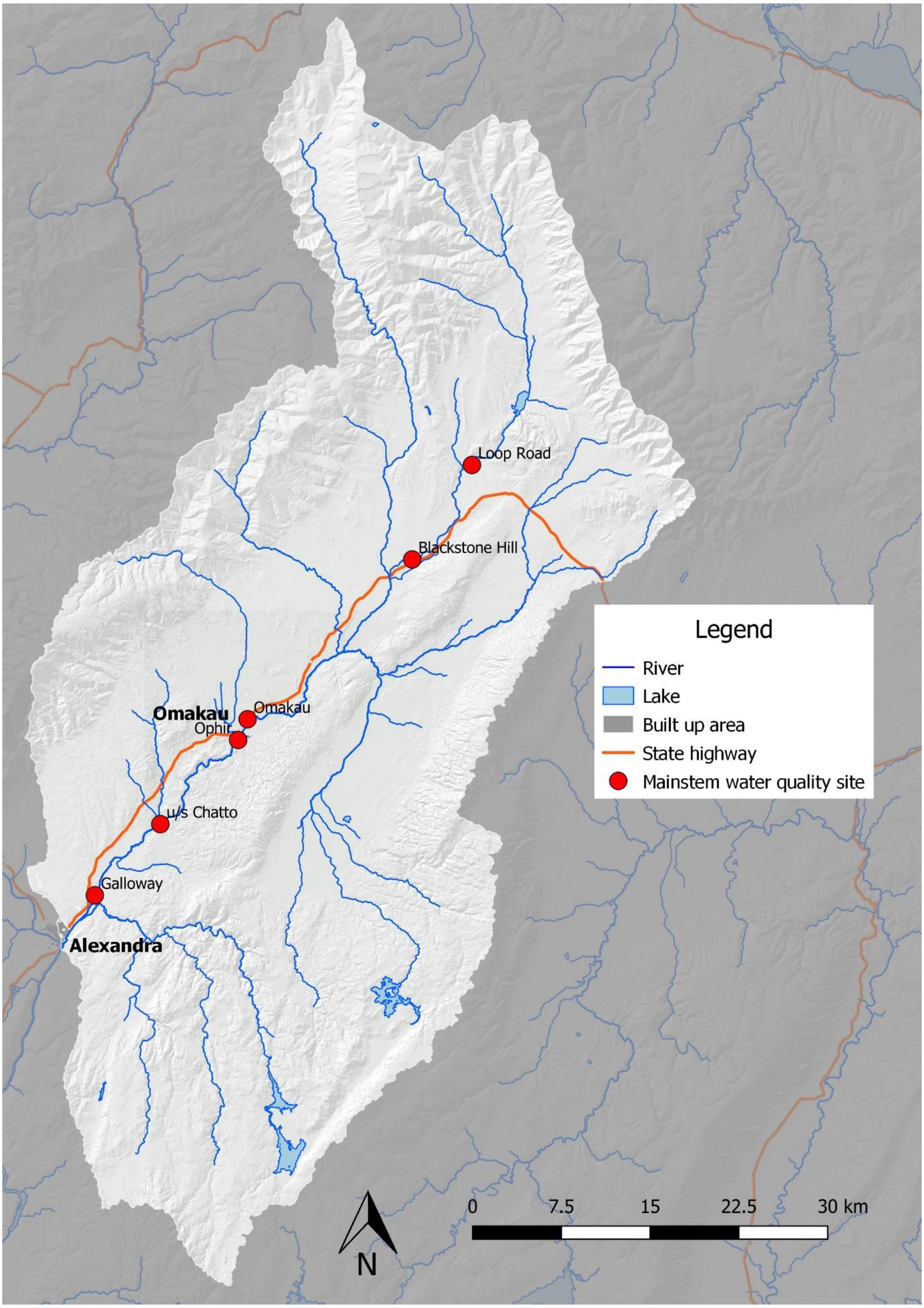

Figure 16 Map of the Manuherikia catchment showing the location of water quality monitoring sites

Each water quality variable was compared to the water quality limits/targets (Schedule 15) contained in the Regional Plan: Water (RPW) (Schedule 15; Receiving Water Group 2; Table 6) as well as the National Objective Framework (NOF) contained in the National Policy Statement for Freshwater Management 2020 (NPSFM). The following section summarises the results of the analyses presented in Hudson & Shelley 2019).

Table 6 Receiving water numerical limits and timeframe for achieving 'good' water quality in the Manuherikia catchment from Schedule 15 of the Regional Plan: Water.

		Nitrate-nitrite nitrogen	Dissolved reactive phosphorus	Ammoniacal nitrogen	Escherichia coli	Turbidity
Manuherikia	Limit/target	0.075 mg/l	0.01 mg/l	0.1 mg/l	260 cfu/100 ml	5 NTU
	Target date	31 March 2012	31 March 2025	31 March 2012	31 March 2012	31 March 2012

Table 7 Attributes and numeric attribute states from the National Objectives Framework.

Attribute	Numeric attribute state	NOF Band A	B	C	D	E	National bottom line
Ammonia (toxicity)	Annual median	≤0.03	>0.03 and ≤0.24	>0.24 and ≤1.30	>1.30	-	**0.24**
	Annual maximum	≤0.05	>0.05 and ≤0.40	>0.40 and ≤2.20	>2.20	-	**0.4**
Nitrate (toxicity)	Annual median	≤1.0	>1.0 and ≤2.4	>2.4 and ≤6.9	>6.9	-	**2.4**
	Annual maximum	≤1.5	>1.5 and ≤3.5	>3.5 and ≤9.8	>9.8	-	**3.5**
Suspended fine sediment (water clarity)	Class 3	≥2.95	<2.95 and ≥2.57	<2.57 and >2.22	<2.22	-	**2.22**
E. coli	% exceedences over 540/100 mL	<5%	5-10%	10-20%	20-30%	>30%	**20%**
	% exceedences over 540/100 mL	<20%	20-30%	20-34%	>34%	>50%	**34%**
	Median concentration	≤130	≤130	≤130	>130	>260	**130**
	95th percentile	≤540	≤1000	≤1200	>1200	>1200	**1200**
Dissolved reactive phosphorus	Median	≤0.006	>0.006 and ≤0.010	>0.010 and ≤0.018	>0.018	-	-
	95th percentile	≤0.021	>0.021 and ≤0.030	>0.030 and ≤0.054	>0.054	-	-
E. coli (primary contact sites)	95th percentile	≤130	>130 and ≤260	>260 and ≤540	>540	-	**540**

5.1.1. Loop Road

The water quality data available for Manuherikia at Loop Road indicates that this site is characterised by low concentrations of ammoniacal nitrogen, nitrate-nitrite nitrogen (NNN), dissolved reactive phosphorus (DRP), and the faecal indicator bacterium Escherichia coli (Table 9). Turbidity readings varied from 0.3 to 20 NTU, although the 80th percentile turbidity (1.28 NTU) indicates that water clarity at this site is typically moderate (Table 9).

The limited amount of water quality data for this means that comparisons to the Schedule 15 water quality limits should be interpreted with caution. However, given the very low concentrations observed at this site, all variables appear to be well within the Schedule 15 limits (Table 9). Based on the limited data available for this site, ammoniacal nitrogen and nitrate-nitrogen concentration were in the A-band, while water clarity was in the C-band (2.43) of the National Objectives Framework (NOF).

5.1.2. Blackstone Hill

The water quality data available for Manuherikia at Blackstone Hill indicated that this site had low concentrations of ammoniacal nitrogen, nitrate-nitrite nitrogen (NNN), and dissolved reactive phosphorus (DRP) (Table 9). Concentrations of the faecal indicator bacterium *Escherichia coli* were within the Schedule 15 limit of 260 cfu/100 mL during periods of low flow (Table 9). Turbidity readings varied from 0.9 to 161 NTU, although the median turbidity (2.3 NTU) indicates that water clarity at this site is typically moderate to low (Table 9).

Observed water quality at this site, suggests that the levels of all variables were within the Schedule 15 limits over the period considered (July 2014-February 2019) (Table 9). Based on the water quality data available for this site, ammoniacal nitrogen and nitrate-nitrogen concentration were in the A-band. Concentrations in the A-band of the nitrate (toxicity) attribute table in the NOF are unlikely to be toxic to sensitive aquatic life.

Concentrations of *E. coli* were in the A-band (Blue) over the 2014/18 period and B-band (Green) in the 2015/19 period (Hudson & Shelley 2019). *E. coli* concentrations in the A-band indicate a very low risk of infection (0.1% risk at least half the time, average risk of infection is 1%), while concentrations in the B-band indicate a low level of risk (0.1% risk at least half the time, average risk of infection is 2%).

The NPSFM includes an attribute for water clarity (horizontal black disc visibility, m) based on Suspended Sediment class (based on the River Environment Classification of climate, topography and geology). The attribute state is based on the median value based on at least five years, either from a record from a continuous turbidity logger, or based on at least 5 years of monthly data.

The Manuherikia is classified as having a cool-dry climate (CD), mountain source (M), and hard sedimentary geology (HS), meaning that it is in Suspended Sediment Class 3 for comparison with the Suspended Sediment attribute table in the NOF (Table 23 of Appendix 2C of the NPSFM). Turbidity data for the Manuherikia at Blackstone Hill were converted to water clarity using a turbidity-clarity relationship developed using data from two sites on the Manuherikia River[26]. The estimated median value for the 5-year period was 1.61 m, which puts it in the D-band of the NOF (i.e. below the national

[26] Water clarity = 2.8149*Turbidity$^{-0.669}$. This relationship is based on concurrent black disc and turbidity readings from Manuherikia at Blackstone Hill (n=35) and Manuherikia at Galloway (n=41) over the period 23 July 1997-14 March 2005.

bottom line for this attribute; <2.22 m). The description of D-band for water clarity in the NOF states "*High impact of suspended sediment on instream biota. Ecological communities are significantly altered and sensitive fish and macroinvertebrate species are lost or at high risk of being lost.".*

Tributaries are likely to be the primary source of suspended sediment in the Manuherikia, as a result of historical gold mining activities or contemporary flood irrigation. Observations suggest that a key source of fine sediment entering the Manuherikia above Blackstone Hill is the aptly named Muddy Creek. The source of the sediment coming from Muddy Creek is not water use related but is from historic gold mining workings, which will require site specific interventions if they are to be reduced. Conversion of flood irrigation to spray irrigation is expected to reduce the input of sediment, DRP and *E. coli* to waterways.

5.1.3. Manuherikia at Omakau

The water quality data available for Manuherikia at Omakau indicated that this site had low concentrations of ammoniacal nitrogen and NNN (Table 9). Low flow concentrations of DRP were slightly elevated (0.0128 mg/L) relative to the Schedule 15 limit (Table 9). Concentrations of *E. coli* (170 cfu/100 mL) were within the Schedule 15 limit of 260 cfu/100 mL during periods of low flow (Table 9). Turbidity readings varied from 0.8 to 160 NTU, although the median turbidity (2.7 NTU) indicates that water clarity at this site is typically moderate to low (Table 9).

Observed water quality at this site, suggests that the levels of all variables except DRP were within the Schedule 15 limits over the period considered (October 2016-February 2019) (Table 9) Based on the water quality data available for this site, ammoniacal nitrogen and nitrate-nitrogen concentration were in the A-band. Concentrations in the A-band of the nitrate (toxicity) attribute table in the NOF are unlikely to be toxic to sensitive aquatic life.

Comparison of *E. coli* concentrations for a waterbody with the NOF attribute table for *E. coli* requires a minimum of 60 samples collected over a maximum of 5 years on a regular basis irrespective of weather and flow conditions. The available data for the Manuherikia at Omakau site falls well short of these requirements, so it is not possible to compare data from this site with the NOF attribute table for *E. coli*.

The estimated median water clarity for the 18 month period available for the Manuherikia at Omakau site was 1.47 m[27], which puts it in the D-band of the NOF (i.e. below the national bottom line for this attribute; <2.22 m). The description of D-band for water clarity in the NOF states "*High impact of suspended sediment on instream biota. Ecological communities are significantly altered and sensitive fish and macroinvertebrate species are lost or at high risk of being lost.".* However, it should be kept in mind that this is based on limited data for this site.

5.1.4. Manuherikia at Ophir

The water quality data available for Manuherikia at Ophir indicated that this site had low concentrations of ammoniacal nitrogen and nitrate-nitrite nitrogen (NNN) (Table 9). Low flow concentrations of DRP were elevated (0.034 mg/L) relative to the Schedule 15 limit (0.01 mg/L) (Table

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[27] Estimated using the regression: Water clarity = 2.8149*Turbidity$^{-0.669}$. This relationship is based on concurrent black disc and turbidity readings from Manuherikia at Blackstone Hill (n=35) and Manuherikia at Galloway (n=41) over the period 23 July 1997-14 March 2005.

9). Concentrations of the faecal indicator bacterium *Escherichia coli* (340 cfu/100 mL) exceeded the Schedule 15 limit of 260 cfu/100 mL during periods of low flow (Table 9). Turbidity readings varied from 1.01 to 220 NTU, although the median turbidity (2.7 NTU) indicates that water clarity at this site is typically low (Table 9).

Observed water quality at this site, suggests that the levels of all variables were within the Schedule 15 limits over the 5-year period considered (February 2014-February 2019) (Table 9). Based on the water quality data available for this site, ammoniacal nitrogen and nitrate-nitrogen concentration were in the A-band of the NOF. Concentrations in the A-band of the nitrate (toxicity) attribute are unlikely to be toxic to sensitive aquatic life.

Based on the analysis of Hudson & Shelley (2019), concentrations of *E. coli* at the Ophir monitoring site were in the C-band in the 2009/13 and 2013/17 periods and in the D-band (Orange) over the 2010/14, 2012/16, 2014/18 and 2015/19 periods. The periods in which this site fell within the D-band (orange) range, resulted from the 95th percentile exceeding 1,200 cfu/100 mL, although in the 2010/14 period, the percentage of values exceeding 260 cfu/100 mL was also in D-band (Table F1 of Hudson & Shelley 2019). *E. coli* concentrations in the C-band (Yellow) indicate a low risk of infection (0.1% risk at least half the time, average risk of infection is 3%), while concentrations in the D-band (Orange) indicate a low level of risk (>5% risk at least half the time, average risk of infection is>3%).

The NOF grades for *E. coli* in the Manuherikia at Ophir are based on year-round sampling undertaken regardless of weather and flows. However, contact recreation in the Manuherikia is constrained by climate and flow conditions. For example, a report commissioned by ORC on the recreational use of the Manuherikia catchment reports that respondents identified flows of up to 4 m^3/s as favoured for swimming (Greenaway 2020), while higher flows may even be hazardous for swimming (due to reduced visibility, swift currents). In addition, swimming is likely to be constrained by water temperatures, with temperatures below 15°C likely to be too cold for swimming without wearing a wetsuit, with maximum cold-shock occurring at water temperatures between 10-15°C[28]. Suitable temperatures for swimming are expected to occur between November and late March (Olsen *et al*. 2017). In addition, mean daily air temperatures at Alexandra are less than 10°C between May and September (Macara 2015). The trout fishing season is 1 October to 30 April. Based on the above, contact recreation is likely to occur between October and April.

To consider a more realistic view of the risk to contact recreation, *E. coli* data from the period 18 February 2014 - 11 February 2019 was considered for occasions when flows were <10 m^3/s (Figure 17). Over this period, three values (11%) exceeded 540 cfu/100 mL (Band C, Yellow), eight values (29%) exceeded 260 cfu/100 mL (Band C, Yellow), the median concentration of *E. coli* was 130 cfu/100 mL (Bands A-C) and the 95th percentile was 762 cfu/100 mL (B-band). Overall, on this basis, this site is in C-band (Yellow) during the period when contact recreation is likely to occur.

[28] http://www.coldwatersafety.org/WhatIsCold.html#DifferentStrokes

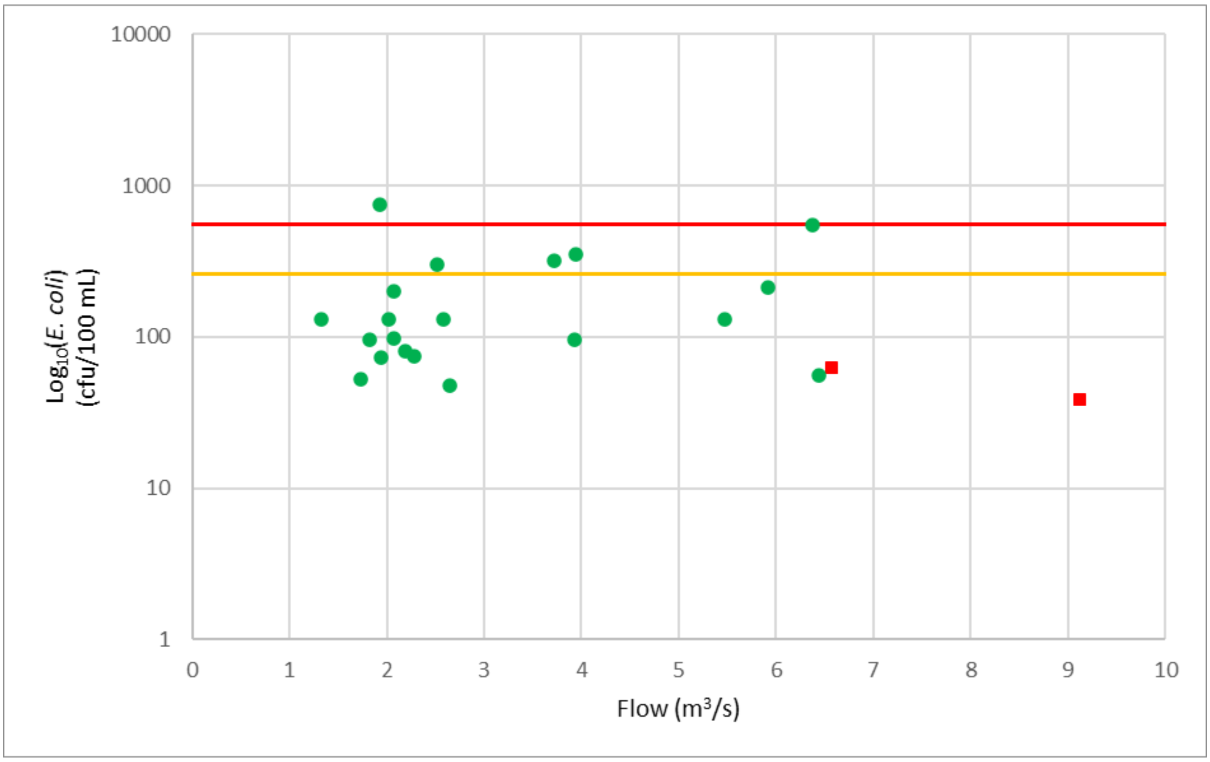

Figure 17 Relationship between flow and* E. coli *concentration in the Manuherikia River at flows of <10 m^3/s. Red points = May-September, Green points = October-April. The orange line is 260 cfu/100 mL, the guideline for primary contact recreation, while the red line is 540 cfu/100 mL, the upper guideline for primary contact recreation (i.e. values >540 cfu/100 mL are considered unsuitable for primary contact recreation).

The estimated median water clarity for the 5-year period 2015/19 was 1.45 m, which puts it in the D-band of the NOF (i.e. below the national bottom line for this attribute; <2.22 m). The description of D-band for water clarity in the NOF states "*High impact of suspended sediment on instream biota. Ecological communities are significantly altered and sensitive fish and macroinvertebrate species are lost or at high risk of being lost.".*

The Omakau monitoring site is located upstream of the discharge from the Omakau wastewater treatment plant (WWTP) discharge and Thomsons Creek confluence, while the Ophir monitoring site is located downstream of both these inflows. Monitoring data collected at these two sites suggests that concentrations of ammoniacal nitrogen (t=-2.24, n=46, p=0.03), NNN (t=-2.27, n=46, p=0.03), and DRP (t=-5.90, n=46, p<0.0001) were higher at Ophir than Omakau, but that *E. coli* counts (t=-1.89, n=20, p=0.07) and turbidity (t=-0.76, n=20, p=0.455) were not significantly different at these two sites (Table 9).

Of these variables, the greatest difference between the two sites was in concentrations of DRP, with the mean concentration at Ophir (0.022 mg/L) almost twice that for the Omakau monitoring site (0.012 mg/L). Comparison of the estimated DRP load from Thomsons Creek with the difference in load between Ophir and Omakau suggests that the load from Thomsons Creek accounted for less than half of the DRP entering the mainstem between the Omakau and Ophir sites on 21 of the 41 sampling occasions for which data was available for all three sites. This suggests that the Omakau WWTP discharge contributes significantly to the DRP load in the mainstem of the Manuherikia from Ophir downstream.

5.1.5. Manuherikia u/s Chatto

The water quality data available for Manuherikia u/s Chatto indicated that this site had low concentrations of ammoniacal nitrogen and NNN (Table 9). Low flow concentrations of DRP were elevated (0.0182 mg/L) relative to the Schedule 15 limit (Table 9). Concentrations of *E. coli* (204 cfu/100 mL) were within the Schedule 15 limit of 260 cfu/100 mL during periods of low flow (Table 9). Turbidity readings varied from 0.56 to 180 NTU, although the median turbidity (3.05 NTU) indicates that water clarity at this site is typically low (Table 9).

Observed water quality at this site, suggests that the levels of all variables except DRP were within the Schedule 15 limits over the period considered (October 2016-May 2018) (Table 9). Based on the water quality data available for this site, ammoniacal nitrogen and nitrate-nitrogen concentration were in the A-band. Concentrations in the A-band of the nitrate (toxicity) attribute table in the NOF are unlikely to be toxic to sensitive aquatic life.

Comparison of *E. coli* concentrations for a waterbody with the NOF attribute table for *E. coli* requires a minimum of 60 samples collected over a maximum of 5 years collected on a regular basis irrespective of weather and flow conditions. The available data for the Manuherikia u/s Chatto site falls well short of these requirements, so it is not possible to compare data from this site with the NOF attribute table for *E. coli*.

The estimated median water clarity for the 18 month period available for the Manuherikia u/s Chatto site was 1.35 m[29], which puts it in the D-band of the NOF (i.e. below the national bottom line for this attribute; <2.22 m). The description of D-band for water clarity in the NOF states "*High impact of suspended sediment on instream biota. Ecological communities are significantly altered and sensitive fish and macroinvertebrate species are lost or at high risk of being lost.".* However, it should be kept in mind that this is based on limited data for this site.

5.1.6. Manuherikia at Galloway

The water quality data available for Manuherikia at Galloway indicated that this site had low concentrations of ammoniacal nitrogen, and nitrate-nitrite nitrogen (NNN) (Table 9). Low flow concentrations of DRP were elevated (0.0182 mg/L) relative to the Schedule 15 limit (Table 9). Concentrations of the faecal indicator bacterium *Escherichia coli* (230 cfu/100 mL) meets the Schedule 15 limit of 260 cfu/100 mL during periods of low flow (Table 9). Turbidity readings varied from 1.13 to 200 NTU, although the median turbidity (2.6 NTU) indicates that water clarity at this site is typically low (Table 9).

Observed water quality at this site, suggests that the levels of all variables were within the Schedule 15 limits over the 5-year period considered (February 2014-February 2019) (Table 9). Based on the water quality data available for this site, ammoniacal nitrogen and nitrate-nitrogen concentration were in the A-band. Concentrations in the A-band of the nitrate (toxicity) attribute table in the NOF are unlikely to be toxic to sensitive aquatic life.

Based on the analysis of Hudson & Shelley (2019), concentrations of *E. coli* at the Galloway monitoring site were in the C-band in all years except 2015/19 when it was in the D-band (Orange). During the

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[29] Estimated using the regression: Water clarity = 2.8149*Turbidity$^{-0.669}$. This relationship is based on concurrent black disc and turbidity readings from Manuherikia at Blackstone Hill (n=35) and Manuherikia at Galloway (n=41) over the period 23 July 1997-14 March 2005.

periods in which this site fell within the C-band (yellow) range, this was a result of 10-20% of readings exceeding 540 cfu/100 mL and/or the 95th percentile exceeding 1,200 cfu/100 mL (Table F1 of Hudson & Shelley 2019). *E. coli* concentrations in the C-band (Yellow) indicate that half of the time, the risk of infection is low (0.1%), but that the average risk of infection is 3%. In the 2015/19 period when this site was in D-band (Orange), this was a result of the 95th percentile exceeding 1,200 cfu/100 mL. Other attribute states over this period were in A-band (% of values exceeding 260 cfu/100 mL = 12% and median value = 45 cfu/100 mL) or B-band (% of values exceeding 540 cfu/100 mL =8%) (Table F1 of Hudson & Shelley 2019). Values in the D-band (Orange) indicate that at least half the time, the risk of infection exceeds 5%, while the average risk of infection is greater than 3%.

The NOF grades for *E. coli* in the Manuherikia at Galloway are based on year-round sampling undertaken regardless of weather and flows. However, as discussed for the Manuherikia at Ophir site above, contact recreation in the Manuherikia is constrained by climate and flow conditions and conditions are not likely to be suitable for contact recreation outside of October and April.

E. coli data from the period 18 February 2014-11 February 2019 was considered for occasions when flows were <10 m^3/s in the months October to April (Figure 17). Over this period, three values (12%) exceeded 540 cfu/100 mL (Band C, Yellow), six values (23%) exceeded 260 cfu/100 mL (Bands B-C, Green/Yellow[30]), the median concentration of *E. coli* was 62 cfu/100 mL (Bands A-C[31]) and the 95th percentile was 690 cfu/100 mL (B-band). Overall, on this basis, this site is in C-band (Yellow) during the period when contact recreation is likely to occur.

The estimated median water clarity for the 5-year period 2015/19 was 1.49 m, which puts it in the D-band of the NOF (i.e. below the national bottom line for this attribute; <2.22 m). The description of D-band for water clarity in the NOF states "*High impact of suspended sediment on instream biota. Ecological communities are significantly altered and sensitive fish and macroinvertebrate species are lost or at high risk of being lost.".*

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[30] An exceedance of 23% of samples over 260 cfu/100 mL meets both the B and C band criteria of the NOF as the bands overlap in their ranges.

[31] A median *E.coli* of 62 cfu/100 mL is in all three bands A – C under the NOF.

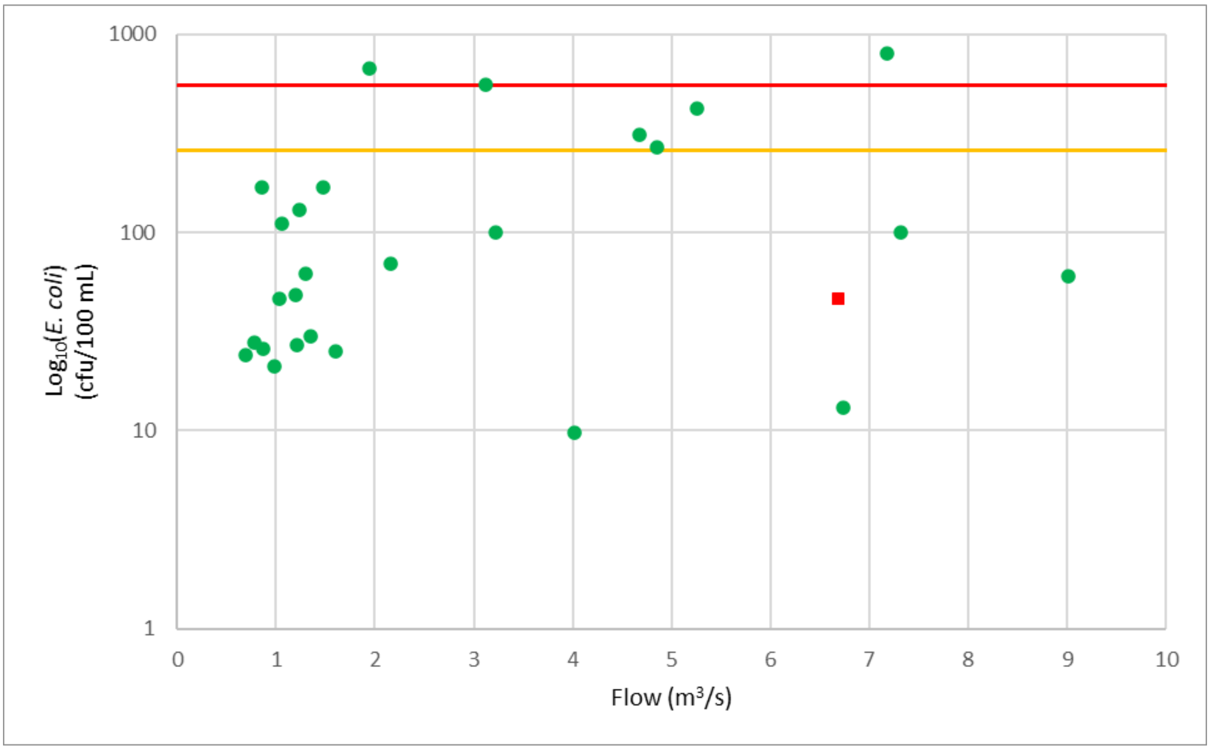

Figure 18 ***Relationship between flow and* E. coli *concentration in the Manuherikia River at Galloway at flows of <10 m³/s between October and April. The orange line is 260 cfu/100 mL, the guideline for primary contact recreation, while the red line is 540 cfu/100 mL, the upper guideline for primary contact recreation (i.e. values >540 cfu/100 mL are considered unsuitable for primary contact recreation).***

5.1.7. Trend analysis

Hudson & Shelley (2019) present an analysis of trends in water quality in the Manuherikia catchment for the period September 2009 – February 2019. This analysis identified possible increasing trends in *E. coli* and NNN, a decreasing trend in DRP, and a possible decreasing trend in turbidity at the Manuherikia at Ophir (Table 8). These findings differ from the results of trend analyses undertaken by Uytendaal & Ozanne (undated) for the Manuherikia at Ophir site over the period July 2006 - June 2017 (Table 59 of Uytendaal & Ozanne, undated), which indicated a significant increasing trend in *E. coli* at this site, but indeterminate trends for all other variables presented (Table 8).

The analysis of Hudson & Shelley (2019) identified an increasing trend in *E. coli*, a decreasing trend in DRP, and possible decreasing trends in NNN and turbidity at the Manuherikia at Galloway (Table 8). These findings are inconsistent with the results of trend analyses undertaken by Uytendaal & Ozanne (undated) for the Manuherikia at Galloway site over the period July 2006-June 2017 (Table 59 of Uytendaal & Ozanne, undated), which indicated increasing trends in DRP and turbidity at this site (Table 8).

The reason(s) for the apparent differences in trends between the analyses of Hudson & Shelley (2019) and those of Uytendaal & Ozanne (undated) are unclear.

Table 8 ***Trend analysis of water quality at the monitoring sites in the Manuherikia River at Ophir and Galloway from the analysis of Hudson & Shelley (2019) and Uytendaal & Ozanne (undated). Hudson & Shelley (2019) presented two analyses – values estimated using seasonal median values (top) and values estimated using all values in each season (bottom).***

Site	Variable	Hudson & Shelley (2019) trend analysis 2009-2019		Uytendaal & Ozanne 2006-2017
		Statistics	Description	
Manuherikia at Ophir	*E. coli*	-	Unlikely	Increasing, Significant
		3.06 (0.90)	Increasing trend possible	
	DRP	4.14 (0.99)	Decreasing trend very likely	Indeterminate / Not Enough Data*
		-2.67 (0.99)		
	NNN	1.05 (0.70)	Increasing trend possible	Indeterminate / Not Enough Data
		1.06 (0.79)		
	Turbidity	1.04 (0.73)	Decreasing trend possible	Indeterminate / Not Enough Data
		1.89 (0.76)		
Manuherikia at Galloway	*E. coli*	1.72 (0.64	Increasing trend possible	Indeterminate / Not Enough Data
		5.09 (0.98)	Increasing trend very likely	
	DRP	-2.88 (0.99)	Decreasing trend virtually certain	Increasing, Significant
		-3.6 (1.0)		
	NNN	-2.68 (0.82)	Decreasing trend possible	Indeterminate / Not Enough Data
		2.91 (0.79)		
	Turbidity	-	Unlikely	Increasing, Probable
		-1.12 (0.80)	Decreasing trend possible	

* = trend analysis conducted on data from August 2011 – June 2017 due to a step-change in laboratory detection limits.

5.1.8. Water quality summary

Concentrations of ammoniacal nitrogen were low at all sites in the Manuherikia River and are below levels that are expected to be toxic to aquatic life. NNN concentrations were very low at sites above the Dunstan Creek confluence (i.e. sites above Blackstone Hill) and higher concentrations were observed at all sites downstream of Omakau, especially at the Ophir site, which is downstream of the discharge from the Omakau waste water treatment plant. Despite NNN being elevated at sites downstream of Omakau, they were still well within the limit set in the Regional Plan: Water (Schedule 15 limit = 0.075 mg/L). Concentrations of DRP were low in the upper catchment but were elevated at sites downstream of Ophir.

Nutrient concentrations increase significantly between the Omakau and Ophir monitoring sites (ammoniacal nitrogen, NNN, and DRP). For example, DRP concentrations at Omakau fall in B-band of the NOF, while they are in the C-band at Ophir. The relatively short distance between these two monitoring sites, narrows the potential sources of this deterioration in water quality to the Omakau WWTP discharge and Thomsons Creek. It is recognised that the water quality in Thomsons Creek is degraded, but analysis suggests that on most occasions, the nutrient load from Thomsons Creek accounts for less than half the difference in DRP concentration between the Omakau and Ophir sites. This analysis suggests that even if the existing declining trend in DRP in Thomsons Creek[32] continues,

[32] Based on the analysis of Hudson & Shelley (2019)

sites downstream of the Omakau WWTP will continue to have elevated DRP concentrations compared with sites upstream of the Omakau monitoring site.

Nutrient concentrations observed in upper Manuherikia River are low, meaning that the risk of nuisance growths of periphyton developing is not materially enhanced by dissolved nutrient concentrations. However, downstream from Ophir, nutrient concentrations are elevated, which is likely to result in an increased risk of periphyton proliferation. Given the presence of the invasive diatom Didymo (*Didymosphenia geminata*), high periphyton biomasses are expected to occur throughout the mainstem due to the preference of this species for oligotrophic[33] conditions, long daylight hours and warm water temperatures during summer months, and the naturally long accrual periods between flushing flows. Increases in nutrient concentrations, particularly DRP, downstream are expected to be less favourable for Didymo proliferation (Bothwell *et al.* 2014) and resulting in a periphyton community of more mixed composition (Section 5.2). Water abstraction is not expected to materially affect habitat suitability for Didymo, but will increase the risk of the proliferation of filamentous algae (based on the analysis of Olsen *et al.* 2017). However, the risk of the proliferation of filamentous algae may be reduced by the anticipated reduction in DRP concentrations resulting from the conversion of flood irrigation to spray irrigation, and this may increase the risk of didymo dominating the periphyton community at more sites in the mainstem.

Concentrations of *E. coli* at the Blackstone Hill indicate a low level of faecal contamination in the upper catchment, meaning that the general water quality is suitable for contact recreation (i.e. primary or secondary contact). Faecal contamination at the Ophir site renders it unsuitable for primary (18-40% of occasions) and/or secondary (10-14% of occasions) contact recreation at times , although most of the time, *E. coli* concentrations at this site are low (median: 86-130 cfu/100 mL). Similarly, the Galloway site is unsuitable for primary (12-23% of occasions) and/or secondary (8-16% of occasions) contact recreation at times due to faecal contamination, although most of the time, *E. coli* concentrations at this site are low (median: 0.81-101 cfu/100 mL). Insufficient *E. coli* data was available for other mainstem sites, meaning that it is not possible to assess the suitability of these sites for contact recreation (i.e. primary or secondary contact).

Water clarity in the Manuherikia at all sites downstream of Blackstone Hill was poor, with low water clarity/high levels of fine sediment (median turbidity >2.3 NTU, median estimated clarity <1.6 m), which can affect many aspects of the stream ecosystems (e.g. shading the stream bed, changing instream habitat by smothering the streambed, directly damaging the gills of macroinvertebrates and/or fish. Water clarity in the Manuherikia at Loop Road site is graded in Band C of the NOF, which is somewhat surprising given its location, approximately 6.5 km downstream of Falls Dam. The catchment upstream of this point is relatively undeveloped, suggesting that the Manuherikia downstream of Falls Dam may have relatively low water clarity in the absence of anthropogenic sources of fine sediments. The reduction in median water clarity between Loop Road and Blackstone Hill (-0.82 m, -33%) is much greater than the differences between sites downstream (range: -0.15 cm to +0.13 cm, -9% to +10%), suggesting that the primary source of the sediment occurs upstream of Blackstone Hill site. This suggests that the primary source of suspended sediment in the Manuherikia occurs between the Loop Road and Blackstone Hill sites. Observations suggest that a key source of fine sediment entering the Manuherikia above Blackstone Hill is the aptly named Muddy Creek. The source of the sediment coming from Muddy Creek is not related to irrigation or water use but is from historic gold mining workings, which will require site specific interventions if they are to be reduced. Meanwhile, conversion of flood irrigation to spray irrigation is expected to continue to reduce the

[33] Low nutrient

input of sediment, DRP and *E. coli* to tributaries (e.g. Chatto, Thomsons and Lauder Creeks) and, consequently, on to the mainstem.

The Manuherikia (Figure 19) and many of its tributaries are known to have a natural brown hue, particularly in the lower reaches of tributaries, and this needs to be considered when assessing clarity based on turbidity under the NOF[34]. Further discussion with ORC on the appropriateness of the NOF bottom lines for clarity and the use of turbidity for this attribute in the Manuherikia catchment would be welcomed.

Figure 19. Brown hue of the Manuherikia at Shaky Bridge (flow less than 1.5 m^3/s).

[34] Table 8 of the NOF list naturally occurring processes such as naturally highly coloured brown-water streams and section 3.32 of the NPSFM anticipates instances where natural processes prevent meeting the national bottom line.

Table 9 ***Summary of water quality at six sites in the Manuherikia River. * = water clarity was estimated from turbidity readings. Data courtesy of ORC.***

Variable **Unit**	**Ammoniacal nitrogen** **mg/L**	**NNN** **mg/L**	**DRP** **mg/L**	***E. coli*** **cfu/100 mL**	**Turbidity** **NTU**	**Clarity*** **m**
Schedule 15 limit	**0.1**	**0.075**	**0.01**	**260**	**5**	**-**
Manuherikia Loop Road						
Median	0.005	0.002	0.003	17	1.2	2.43
Min	0.005	0.001	0.001	1	0.3	0.38
Max	0.010	0.126	0.011	100	20.0	6.44
5-year 95th percentile	0.006	0.061	0.008	100	14.1	5.12
5-year 80th percentile (low flows)	0.005	0.004	0.003	24	1.3	
Manuherikia at Blackstone Hill						
Median	0.005	0.004	0.004	35	2.3	1.61
Min	0.005	0.001	0.001	2	0.9	0.09
Max	0.073	0.210	0.020	2400	161.0	3.02
5-year 95th percentile	0.017	0.076	0.011	791	117.0	2.93
5-year 80th percentile (low flows)	0.006	0.005	0.004	182	4.6	
Manuherikia at Omakau						
Median	0.005	0.028	0.009	98	2.7	1.47
Min	0.005	0.001	0.001	2	0.9	0.09
Max	0.020	0.450	0.029	5400	160.0	3.27
5-year 95th percentile	0.019	0.315	0.027	4850	117.5	2.96
5-year 80th percentile (low flows)	0.006	0.005	0.004	182	4.6	
Manuherikia at Ophir						
Median	0.010	0.045	0.013	96	2.7	1.45
Min	0.005	0.001	0.001	5	1.0	0.08
Max	0.021	0.440	0.081	4900	220.0	2.80
5-year 95th percentile	0.034	0.278	0.047	1300	81.7	2.42
5-year 80th percentile (low flows)	0.019	0.034	0.045	340	2.8	
Manuherikia u/s Chatto						
Median	0.005	0.028	0.012	105	3.1	1.35
Min	0.005	0.002	0.001	18	0.6	0.09
Max	0.063	0.440	0.050	5900	180.0	4.15
5-year 95th percentile	0.037	0.365	0.041	4100	168.0	3.78
5-year 80th percentile (low flows)	0.007	0.018	0.023	204	1.8	
Manuherikia at Galloway						
Median	0.006	0.023	0.010	46	2.6	1.5
Min	0.005	0.001	0.001	7	1.1	0.1
Max	0.020	0.440	0.042	5700	200.0	3.8
5-year 95th percentile	0.025	0.216	0.026	1064	157.8	3.2
5-year 80th percentile (low flows)	0.010	0.018	0.022	230	2.1	

5.2. Periphyton

The ORC has been undertaking monthly periphyton monitoring at three sites on the Manuherikia mainstem (Blackstone Bridge, Ophir and Galloway) and one site on Dunstan Creek (Beattie Road) since February 2019. This monitoring consists of assessment of periphyton cover (RAM-2) and biomass (chlorophyll-*a*).

In addition, ORC commissioned periphyton monitoring at six locations on the Manuherikia River in the summer of 2016-2017: Downstream of Fork (upstream of Falls Dam), Loop Road, Blackstone Hill, Omakau, Ophir and Galloway.

5.2.1. Periphyton cover and composition

Between 18 February 2019 and 24 May 2020, periphyton cover as a percentage of the bed at Blackstone Hill ranged from 4% to 87% (mean = 54%) (Table 10). Cover was dominated by long filamentous green algae on five of the fourteen survey occasions (36%), all in the months of February-April, with cover reaching as high as 45% (Table 10). Medium and thick light brown mats dominated on seven other occasions (Table 10), with cover likely dominated by the invasive diatom *Didymosphenia geminata* on these occasions.

Table 10. Summary of periphyton cover (%) at Manuherikia River at Blackstone Hill over the period 18 February 2019 to 24 May 2020 (N=14). Data courtesy of Otago Regional Council.

Category	Thickness	% cover		
		Min	Max	Mean
Thin green film	<0.5mm	0	2	0
Thin light brown film	<0.5mm	0	32	9
Thin black/dark brown film	<0.5mm	0	1	0
Medium green mat	0.5-3mm	0	0	0
Medium light brown mat	0.5-3mm	0	48	12
Medium black/dark brown mat	0.5-3mm	0	0	0
Thick green/light brown mat	>3mm	0	58	16
Thick black/dark brown mat	>3mm	0	0	0
Short green filaments	<2cm	0	22	3
Short brown/reddish filaments	<2cm	0	9	1
Long green filaments	>2cm	0	45	13
Long brown/reddish filaments	>2cm	0	0	0
Total algal % cover		4	87	54

Between 18 February 2019 and 24 May 2020, periphyton cover at Ophir ranged from 3% to 98% (mean = 56%) (Table 10). Cover was dominated by thin light brown films on seven of the twelve survey occasions (58%) (Table 11). Cover was dominated (28%) by long brown/reddish filaments (>2 cm) on one occasion (21 January 2020) (Table 11).

Table 11. Summary of periphyton cover (%) at Manuherikia River at Ophir over the period 18 February 2019 to 24 May 2020 (N=12). Data courtesy of Otago Regional Council.

Category	Thickness	% cover		
		Min	Max	Mean
Thin green film	<0.5mm	0	58	10
Thin light brown film	<0.5mm	1	87	31
Thin black/dark brown film	<0.5mm	0	5	1
Medium green mat	0.5-3mm	0	0	0
Medium light brown mat	0.5-3mm	0	15	4
Medium black/dark brown mat	0.5-3mm	0	10	2
Thick green/light brown mat	>3mm	0	8	1
Thick black/dark brown mat	>3mm	0	3	0
Short green filaments	<2cm	0	4	1
Short brown/reddish filaments	<2cm	0	5	1
Long green filaments	>2cm	0	7	2
Long brown/reddish filaments	>2cm	0	28	2
Total algal % cover		3	98	56

Between 18 February 2019 and 24 May 2020, periphyton cover at the Galloway site ranged from 0% to 100% (mean = 58%) (Table 10). Cover was dominated by thin light brown films on eight of the thirteen survey occasions (62%) (Table 11). High cover (>25%) by long green filamentous algae (>2 cm) occurred on two occasions (18 March 2019 and 20 March 2020) (Table 11).

Table 12. Summary of periphyton cover (%) at Manuherikia River at Galloway over the period 18 February 2019 to 24 May 2020 (N=13). Data courtesy of Otago Regional Council.

Category	Thickness	% cover		
		Min	Max	Mean
Thin green film	<0.5mm	0	9	2
Thin light brown film	<0.5mm	0	97	43
Thin black/dark brown film	<0.5mm	0	21	3
Medium green mat	0.5-3mm	0	0	0
Medium light brown mat	0.5-3mm	0	7	2
Medium black/dark brown mat	0.5-3mm	0	2	0
Thick green/light brown mat	>3mm	0	11	1
Thick black/dark brown mat	>3mm	0	1	0
Short green filaments	<2cm	0	1	0
Short brown/reddish filaments	<2cm	0	0	0
Long green filaments	>2cm	0	44	6
Long brown/reddish filaments	>2cm	0	0	0
Total algal % cover		0	100	58

5.2.2. Periphyton biomass

Periphyton biomass was estimated as chlorophyll-*a* concentration at Downstream of Forks, Loop Road, Blackstone Hill, Ophir and Galloway on four occasions in 2016/17 (Figure 20, Figure 21, Figure 22,) and monthly at Blackstone Hill (Figure 23), Ophir (Figure 24) and Galloway (Figure 25) from February 2019 to May 2020 (Figure 23).

Periphyton biomass was low at the Downstream of Forks and Blackstone Hill sites on all four occasions sampled in 2016/17 (Figure 20, Figure 22), whilst the biomass at Loop Road on 31 March 2017 (124 mg/m^2) and 26 April 2018 (67 mg/m^2) was moderate-high (Figure 21). Periphyton cover at Loop Road on both occasions was dominated by green/light brown mats, likely to be dominated by the invasive diatom *Didymosphenia geminata*.

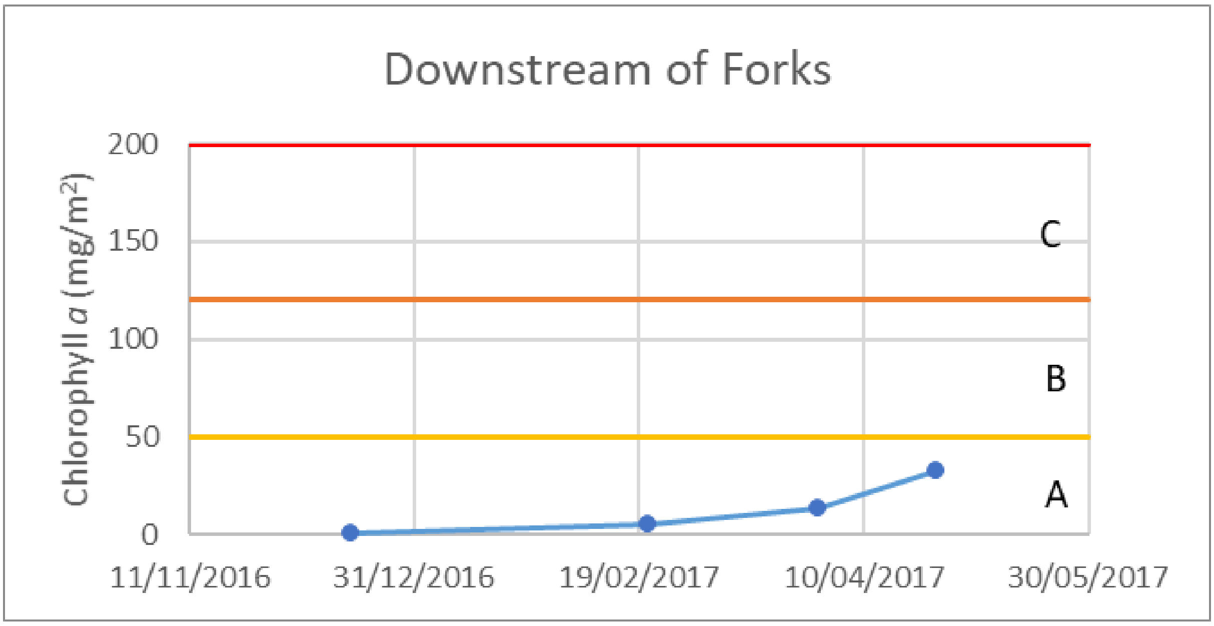

Figure 20. Benthic chlorophyll-a concentration in the Manuherikia River at Downstream of Forks from December 2016 to April 2017. Letters on the righthand side of the plot represent NOF bands for periphyton (trophic state). Data courtesy of ORC.

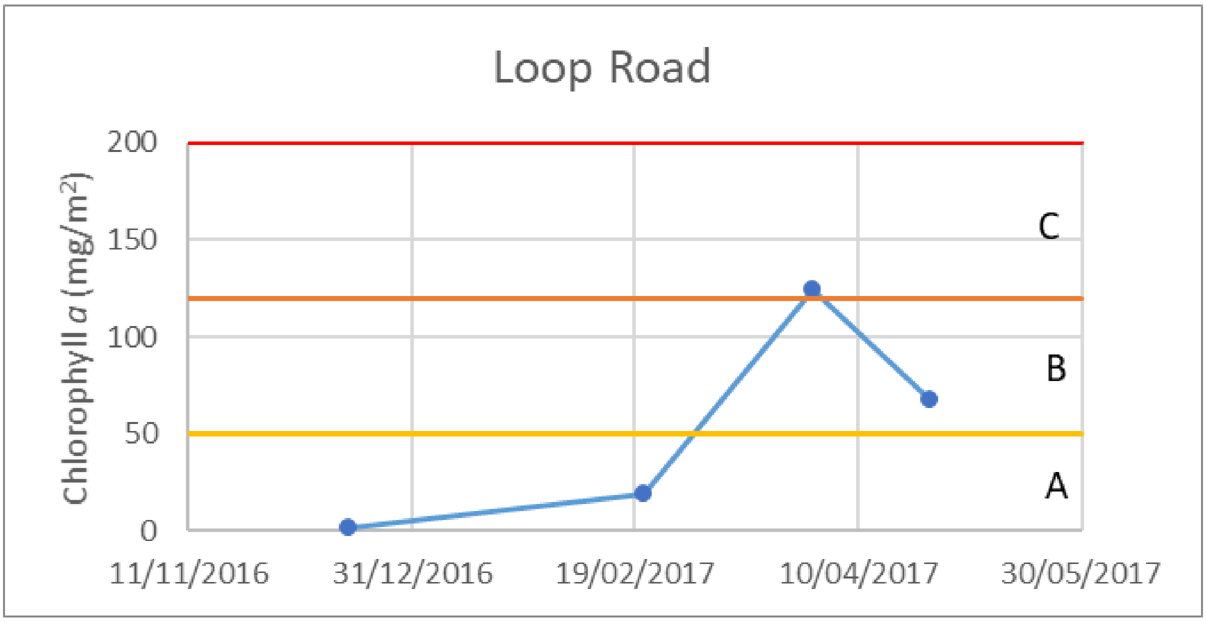

Figure 21. Benthic chlorophyll-a concentration in the Manuherikia River at Loop Road from December 2016 to April 2017. Letters on the righthand side of the plot represent NOF bands for periphyton (trophic state). Data courtesy of ORC.

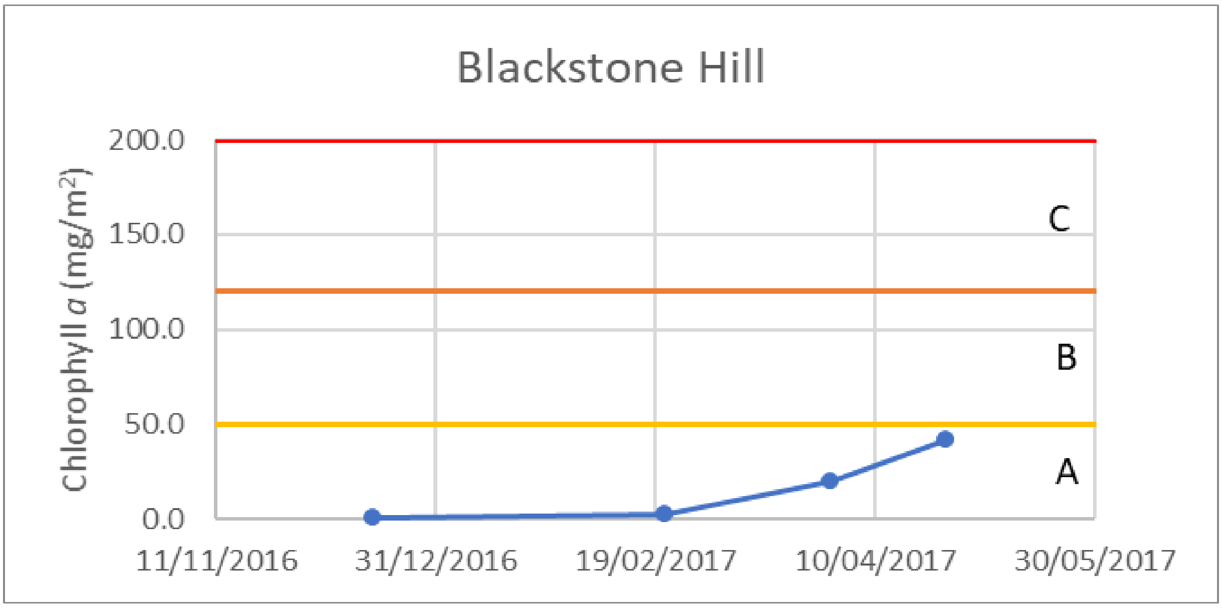

Figure 22. Benthic chlorophyll-a concentration in the Manuherikia River at Blackstone Hill from December 2016 to April 2017. Letters on the righthand side of the plot represent NOF bands for periphyton (trophic state). Data courtesy of ORC.

Periphyton biomass in the Manuherikia River at Blackstone Hill over the period 18 February 2019 to 24 May 2020 was typically low (<50 mg/m^2), with the higher concentrations (43-71 mg/m^2) observed in autumn (March-May)(Figure 23).

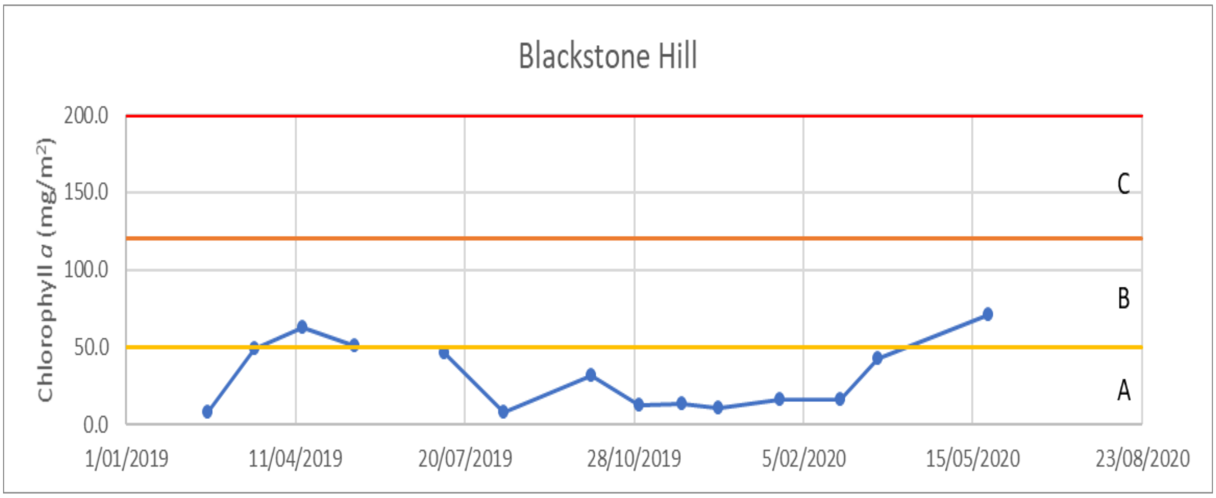

Figure 23. Benthic chlorophyll-a concentration in the Manuherikia River at Blackstone Hill from 18 February 2019 to 24 May 2020. Letters on the righthand side of the plot represent NOF bands for periphyton (trophic state). Data courtesy of ORC.

Periphyton biomass in the Manuherikia River at Ophir over the period 18 February 2019 to 24 May 2020 was typically low (<50 mg/m^2) (Figure 24). The chlorophyll-*a* concentration observed on 16 May 2019 (74 mg/m^2) exceeded the guideline for the protection of benthic biodiversity (Biggs 2000), while the value on 22 January 2020 (129.6 mg/m^3) exceeded the guidelines for aesthetics/recreation and trout habitat and angling (Biggs 2000) (Figure 24), with cover on this occasion dominated by filamentous algae (total cover ~40%).

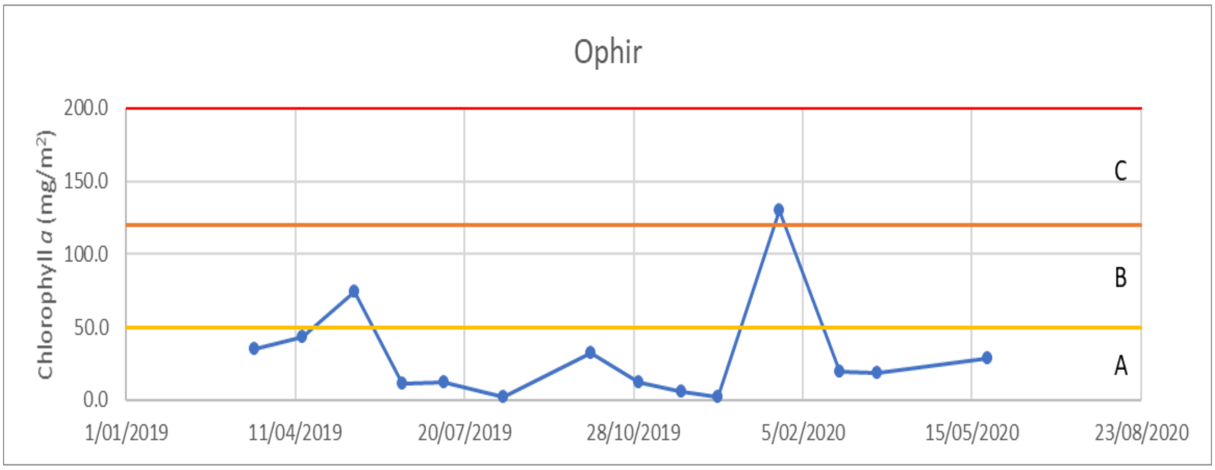

Figure 24. Benthic chlorophyll a concentration in the Manuherikia River at Ophir from 18 February 2019 to 24 May 2020. Letters on the righthand side of the plot represent NOF bands for periphyton (trophic state). Data courtesy of ORC.

Periphyton biomass in the Manuherikia River at Galloway over the period 18 February 2019 to 24 May 2020 was low (<50 mg/m^2) on most occasions (Figure 25). The chlorophyll *a* concentration observed on 16 May 2019 (161 mg/m^2) exceeded the guideline for aesthetics/recreation and trout habitat and angling (Biggs 2000). Periphyton cover on this occasion was low (average cover 23%), but dominated by Didymo (11%). Periphyton biomass on 27 February 2020 (76 mg/m^2) and 20 March 2020 (65 mg/m^2) exceeded the guideline for the protection of benthic biodiversity (Biggs 2000) (Figure 15).

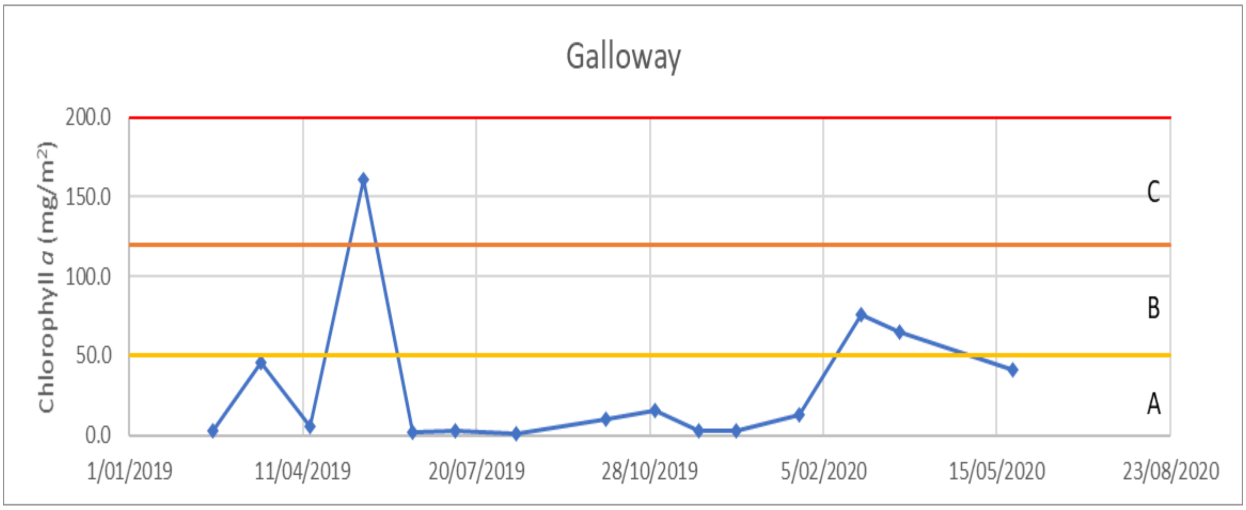

Figure 25. Benthic chlorophyll a concentration in the Manuherikia River at Galloway from 18 February 2019 to 24 May 2020. Letters on the righthand side of the plot represent NOF bands for periphyton (trophic state). Data courtesy of ORC.

The NOF includes a periphyton (trophic state) attribute, as measured by the chlorophyll-*a* biomass based on a monthly monitoring regime of at least 3 years (i.e. N=36). None of the available datasets are long enough to enable this analysis. However, the available data for Blackstone Hill (N=18), Ophir (N=14) and Galloway (N=15) indicate that all three sites are in B-band (92nd percentiles[35]: Blackstone = 63 mg/m^2, Ophir = 77.8 mg/m^2, Galloway = 76 mg/m^2; Table 2 of the NOF, NPSFM 2020).

5.2.3. Periphyton summary

ORC has undertaken monthly monitoring of periphyton cover and biomass at Blackstone Bridge, Ophir and Galloway since February 2019. The invasive diatom Didymo dominated cover at Blackstone Hill on most occasions with long filamentous green algae also dominated cover at this site at times. Consistent with this, the biomass of periphyton was generally low to moderate at the Blackstone Hill site. The periphyton community at the Ophir and Galloway monitoring sites was generally dominated by thin light brown films (likely dominated by diatoms), although filamentous algae dominated both sites on occasion.

Biomass at both sites was low (<50 mg/m^3) on most occasions, although it did exceed guidelines (>120 mg/m^2) on one occasion at each site. At the Ophir site, (22 January 2020; 130 mg/m^2), this was associated with 28% cover of long filamentous algae, whilst at the Galloway site (20 May 2019; 160 mg/m^2) the high biomass was associated with relatively low cover (15%) of medium and thick light brown mats.

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[35] 8% of values exceed the 92nd percentile, as per the Periphyton (trophic state) attribute table (Table 2) of the NOF (NPSFM 2020).

Nutrient concentrations observed in upper Manuherikia River are low, meaning that the risk of nuisance growths of periphyton developing is not materially enhanced by dissolved nutrient concentrations. However, downstream from Ophir, nutrient concentrations are elevated, which is likely to result in an increased risk of periphyton proliferation. Given the presence of the invasive diatom Didymo (*Didymosphenia geminata*), high periphyton biomasses are expected to occur throughout the mainstem due to the preference of this species for oligotrophic[36] conditions, long daylight hours and warm water temperatures during summer months, and the naturally long accrual periods between flushing flows. Increases in nutrient concentrations, particularly DRP, downstream are expected to be less favourable for Didymo proliferation (Bothwell *et al.* 2014) and resulting in a periphyton community of more mixed composition (Section 5.2). Water abstraction is not expected to materially affect habitat suitability for Didymo, but will increase the risk of the proliferation of filamentous algae (based on the analysis of Olsen *et al.* 2017). However, the risk of the proliferation of filamentous algae may be reduced by the anticipated reduction in DRP concentrations resulting from the conversion of flood irrigation to spray irrigation, although this may increase the risk of didymo dominating the periphyton community at more sites in the mainstem.

5.3. Macroinvertebrates

Otago Regional Council undertakes long-term macroinvertebrate sampling at three sites in the mainstem of the Manuherikia River: Blackstone, Ophir and Galloway. In addition, additional sites have been sampled in 2010 (Kitto 2011) and 2016/17 (presented in Hudson & Shelley 2019). Kitto (2011) presented the results of macroinvertebrate sampling (3 Surber samples) undertaken in December 2010 at Loop Road, Blackstone Hill, upstream of the Ida Burn confluence, Omakau, Ophir, upstream of Chatto Creek and Galloway. Further to this, ORC commissioned macroinvertebrate sampling at six sites (downstream of Fork, Loop Road, Blackstone Hill, Omakau, Ophir, and Galloway) on three occasions in 2016 and 2017.

The Macroinvertebrate Community Index (MCI) and its quantitative variant (QMCI) uses the composition of the macroinvertebrate community (as well as the abundance of different taxa in the case of the QMCI) as a measure of water and habitat quality. High scores indicate clean water quality and high habitat quality (MCI > 120, QMCI > 6), while low scores indicate poor water and/or habitat quality (MCI < 80, QMCI < 4) (Stark & Maxted 2007).

5.3.1. Loop Road

During sampling in 2010, the macroinvertebrate community at Loop Road was dominated by EPT[37] taxa (>90%; Kitto 2011), while in samples taken in 2016/17, EPT taxa consisted of 36-41% of the taxa in the samples (Table 13).

During sampling in 2016/17, the macroinvertebrate community in the Manuherikia River at Loop Road was dominated by the mudsnail *Potamopyrgus antipodarum* and oligochaete worms, while on February and April 2017, riffle beetles (Elmidae), chironomid midge larvae, the mayfly *Deleatidium* were also very abundant (Table 13).

[36] Low nutrient

[37] E = Ephemeroptera (mayflies), P = Plecoptera (stoneflies) and T = Trichoptera (caddis flies). These three orders are typically associated with clean, oxygenated water (with the exception of some caddis flies).

The MCI (89-96) and QMCI (3.10-3.90) scores for the Loop Road site in 2016/17 were consistent with poor-fair water and habitat quality (Table 13). The composition of the macroinvertebrate community at Loop Road likely reflects the dominance of the periphyton community at this site by the invasive diatom *Didymosphenia geminata,* which is known to affect macroinvertebrate community composition (Larned *et al.* 2007, Jellyman & Harding 2016).

5.3.2. Blackstone Hill

During sampling in 2010, the macroinvertebrate community at Blackstone Hill was numerically dominated by EPT taxa (>75%; Kitto 2011). During sampling in 2016/17 and 2019, EPT taxa consisted of 44-52% of the taxa in the samples (Table 14). The samples collected by Kitto (2010) gave an average MCI (85) and QMCI (4.00) were consistent with poor-fair water and habitat quality.

The macroinvertebrate community in the Manuherikia River at Blackstone Hill was dominated by the common mayfly *Deleatidium* on most sampling occasions, with *Hydropsyche*[38] also particularly abundant on the February 2019 sampling occasion (Table 14).

MCI scores for the Blackstone Hill site in 2016/17 were consistent with fair-good water and habitat quality (94-105), while SQMCI scores were less consistent, varying from being indicative of fair (4.24 on 17 December 2016) to excellent (7.2 26 April 2017) water and habitat quality (based on the criteria of Stark & Maxted 2007). It is possible that the dominance of the periphyton community at this site by the invasive diatom Didymo affects the composition of the macroinvertebrate community at this site and may account for the low MCI/SQMCI scores observed on occasion.

5.3.3. Upstream of the Ida Burn

During sampling in 2010, the macroinvertebrate community in the Manuherikia River upstream of the Ida Burn was dominated by EPT taxa (c.65%; Kitto 2011). The MCI (c.105) and QMCI (5.00) scores for the upstream of the Ida Burn site in 2010 were consistent with fair-good water and habitat quality (Kitto 2011).

[38] This genus of net-spinning caddis fly has previously been referred to as *Aoteapsyche*, but recent taxonomic revision changed the genus to *Hydropsyche*.

Table 13 ***Macroinvertebrate community composition of the Manuherikia River at Loop Road in 2016, 2017 and 2019. Data courtesy of Otago Regional Council.*** ***Only taxa that were abundant on at least one occasion are shown.***

TAXON	MCI score	Manuherikia River at Loop Road		
		17/12/2016	20/02/2017	26/04/2017
COLEOPTERA				
Elmidae	6	A	VA	VA
CRUSTACEA				
Cladocera	5	R	VA	C
DIPTERA				
Austrosimulium species	3	A		
Empididae	3	R	C	A
Orthocladiinae	2	A		C
Polypedilum species	3		A	VA
Tanytarsini	3	A	VA	VA
EPHEMEROPTERA				
Deleatidium species	8	A	VA	VA
MOLLUSCA				
Potamopyrgus antipodarum	4	VA	VA	VVA
NEMERTEA	3			R
OLIGOCHAETA	1	A	VVA	VVA
PLECOPTERA				
Zelandobius species	5		R	VA
TRICHOPTERA				
Hydropsyche species (*Aoteapsyche*-group)	4	R	C	A
Hydrobiosis species	5	C	A	A
Neurochorema species	6	R		A
Olinga species	9		R	R
Oxyethira albiceps	2	A	VA	A
Psilochorema species	8	C	C	A
Pycnocentria species	7		C	A
Pycnocentrodes species	5	R	C	A
Number of taxa		22	27	30
Number of EPT taxa		8	11	12
% EPT taxa		36	41	40
MCI score		89	96	95
SQMCI score		3.9	3.1	3.5

Table 14 ***Macroinvertebrate community composition of the Manuherikia River at Blackstone Hill in 2016, 2017 and 2019. Data courtesy of Otago Regional Council. Only taxa that were abundant on at least one occasion are shown.***

TAXON	MCI score	Manuherikia River at Blackstone Hill 17/12/2016	20/02/2017	26/04/2017	18/02/2019
COLEOPTERA					
Elmidae	6	A	A	A	C
DIPTERA					
Austrosimulium species	3	A	R	C	A
Orthocladiinae	2	A	A	C	VA
Tanytarsini	3	R	C	R	A
EPHEMEROPTERA					
Austroclima species	9			A	C
Deleatidium species	8	A	VVA	VVA	VVA
OLIGOCHAETA	1	A	VA	A	A
PLECOPTERA					
Zelandobius species	5		C	A	
TRICHOPTERA					
Hydropsyche - Aoteapsyche group	4	R	A	A	VVA
Hydrobiosis species	5	C	C	A	A
Olinga species	9	R		A	C
Pycnocentria species	7		A	VA	A
Pycnocentrodes species	5	A	C	A	
Number of taxa		18	18	25	19
Number of EPT taxa		8	9	13	9
% EPT taxa		44	50	52	47
MCI score		97	94	102	105
SQMCI score		4.2	6.5	7.2	5.5

5.3.4. Omakau

During sampling in 2010, the macroinvertebrate community at Omakau was dominated by EPT[37] taxa (c.60%; Kitto 2011). During sampling in 2016/17 and 2019, EPT taxa consisted of 39-53% of the taxa in the samples (Table 15). The samples collected by Kitto (2010) gave an average MCI (100) and QMCI (c.5.50) were consistent with good water and habitat quality.

The macroinvertebrate community in the Manuherikia River at Omakau was dominated by the common mayfly *Deleatidium* and the cased caddis fly *Pycnocentrodes*, while the mudsnail *Potamopyrgus* also particularly abundant on the April 2019 sampling occasion (Table 15).

MCI scores for the Omakau site in 2016/17 were consistent with good water and habitat quality (100-108), while SQMCI scores were indicative of good to excellent water and habitat quality (5.18-6.07) (based on the criteria of Stark & Maxted 2007).

Table 15 Macroinvertebrate community composition of the Manuherikia River at Omakau in 2016, 2017 and 2019. Data courtesy of Otago Regional Council. Only taxa that were abundant on at least one occasion are shown.

TAXON	MCI score	Manuherikia River at Omakau		
		17/12/2016	26/04/2017	20/02/2017
DIPTERA				
Austrosimulium species	3	A	C	VA
Tanytarsini	3	A		C
EPHEMEROPTERA				
Deleatidium species	8	VA	VVA	VVA
MOLLUSCA				
Potamopyrgus antipodarum	4	C	VVA	A
NEMERTEA	3	R	A	R
OLIGOCHAETA	1	A	VA	A
TRICHOPTERA				
Aoteapsyche species	4	C	A	A
Pycnocentria species	7		A	VA
Pycnocentrodes species	5	VVA	VA	VVA
Number of taxa		23	22	19
Number of EPT taxa		9	11	10
% EPT taxa		39	50	53
MCI score		100	108	107
SQMCI score		5.2	5.5	6.1

5.3.5. Ophir

During sampling in 2010, the macroinvertebrate community at Ophir was dominated by EPT taxa (~55%; Kitto 2011) and an average MCI (90) and QMCI (c.4.00) were consistent with poor to fair water and habitat quality.

During sampling in 2016/17, the macroinvertebrate community in the Manuherikia River at Ophir was dominated by the mayfly *Deleatidium* (Table 16). The mudsnail *Potamopyrgus antipodarum*, oligochaeta, riffle beetles (Elmidae) and various cased caddis (including *Olinga*, *Pycnocentria* and *Pycnocentrodes*). EPT taxa consisted of 39-63% of the taxa in the samples collected in 2016/17, with MCI scores ranging from 93-111, indicating fair-good water quality and SQMCI scores ranging from 3.46-7.21, which indicates water and/or quality between 'poor' and 'excellent' based on the criteria of Stark & Maxted (2007) (Table 16).

The macroinvertebrate community at the Ophir monitoring site was sampled monthly between March 2019 and February 2020. The common mayfly *Deleatidium* dominated the community on all sampling occasions, while the net-spinning caddis fly *Hydropsyche,* mudsnail *Potamopyrgus antipodarum*, riffle beetles (Elmidae) and the cased caddis *Pycnocentrodes* were also among the most abundant taxa at this site. EPT taxa consisted of 39-63% of the taxa in the samples collected in 2019/20, with MCI scores ranging from 93-111, indicating fair-good water quality and SQMCI scores ranging from 6.13-6.91, which indicates excellent water quality (Table 16).

5.3.6. Galloway

During sampling in 2010, the macroinvertebrate community in the Manuherikia at Galloway was dominated by EPT taxa (~25%; Kitto 2011) and an average MCI (90) and QMCI (c.3.50) were consistent with poor to fair water and habitat quality.

During sampling in 2016/17, the macroinvertebrate community in the Manuherikia River at Galloway was dominated by the mayfly *Deleatidium* followed by the mudsnail *Potamopyrgus antipodarum* and the cased caddis *Pycnocentrodes* (Table 16). EPT taxa consisted of 39-50% of the taxa in the samples collected in 2016/17, with MCI scores ranging from 92-97, indicating fair water quality and SQMCI scores ranging from 4.93-6.99, which indicates water and/or quality between fair/good and excellent based on the criteria of Stark & Maxted (2007) (Table 16).

The macroinvertebrate community at the Ophir monitoring site was sampled monthly between March 2019 and February 2020. The common mayfly *Deleatidium* dominated the community on all sampling occasions (Table 16). The net-spinning caddis fly *Hydropsyche* was the next most abundant taxa on most occasions, while the mudsnail *Potamopyrgus antipodarum*, sandfly larvae (*Austrosimulium*) and the cased caddis *Pycnocentrodes* were among the most abundant taxa on some occasions. EPT taxa consisted of 33-64% of the taxa in the samples collected in 2019/20, with MCI scores ranging from 91-110, indicating fair-good water quality and SQMCI scores ranging from 5.58-7.34, which indicates fair/good to excellent water quality (Table 16).

Table 16 ***Macroinvertebrate community composition of the Manuherikia River at Ophir. Data courtesy of Otago Regional Council. Only taxa that were abundant on at least one occasion are shown.***

TAXON	MCI score	Manuherikia River at Ophir											
		18/03/19	15/04/19	20/05/19	13/06/19	8/07/19	12/08/19	3/10/29	31/10/19	25/11/19	17/12/19	22/01/20	27/02/20
COLEOPTERA													
Elmidae	6	A	VA	VA	A	A	R	A	A	VA	VA	VA	A
DIPTERA													
Austrosimulium species	3	A	A	VA	VA	A	A	C	A	A	A	A	C
Orthocladiinae	2	R	C	A	C	C	C	C	A	A	C	A	C
Tanytarsini	3	R	R	C	R		R	C	C	C	A	C	C
EPHEMEROPTERA													
Deleatidium species	8	VVA	VVA	VVA	VVA	VVA	VVA	VVA	VVA	VVA	VVA	VVA	VVA
MOLLUSCA													
Physa / Physella species	3	R	A	A	C	R	C						R
Potamopyrgus antipodarum	4	VA	VA	VA	VA	VA	A	C	VA	A	VA	A	A
OLIGOCHAETA	1	A	C	C	A	A	C	R	C	C		A	A
PLECOPTERA													
Zelandobius species	5	R	A	A	A	A	A	A	A	R	R		R
TRICHOPTERA													
Hudsonema amabile	6	C	A	A	A	A	R	C	R	R	C		R
Hydrobiosis species	5	A	C	A	VA	A	A	C	A	A	A	A	C
Hydropsyche - Aoteapsyche group	4	VA	VVA	VA	VA	VA	VA	VA	VA	VA	VA	VA	VA
Olinga species	9	R	A	C	C	C	R	R	C	R	C	R	
Pycnocentria species	7	VA	A	A	C	C	R	C	C	R		R	A
Pycnocentrodes species	5	VA	VVA	A	A	A	C	VA	VA	VA	VA	A	A
Number of taxa		22	25	22	21	23	23	17	21	22	22	19	23
Number of EPT taxa		11	11	10	11	10	11	9	9	10	9	9	9
% EPT taxa		50	44	45	52	43	48	53	43	45	41	47	39
MCI score		101	97	99	105	100	111	108	97	101	103	96	99
SQMCI score		6.4	5.6	6.1	6.0	6.4	6.9	6.8	6.3	6.5	6.4	6.6	6.8

Table 17 *Macroinvertebrate community composition of the Manuherikia River at Galloway in 2019/20. Data courtesy of Otago Regional Council. Only taxa that were abundant on at least one occasion are shown.*

	MCI score	Manuherikia River at Galloway												
TAXON		18/02/2019	18/03/2019	15/04/2019	20/05/2019	12/06/2019	8/07/2019	12/08/2019	3/10/2019	31/10/2019	25/11/2019	17/12/2019	22/01/2020	27/02/202
ACARINA	5										R			
COLEOPTERA														
Elmidae	6	C	A	C	A	C	R	R	R	R	C	A	A	A
Staphylinidae	5			R										
CRUSTACEA														
Ostracoda	3	R	C	C	A	C	C							
Paracalliope fluviatilis	5	R												
Paraleptamphopus species	5	R								R				
DIPTERA														
Aphrophila species	5									R				
Austrosimulium species	3	VA	C	VA	VA	A	A	C	A	A	A	VA	R	
Ceratopogonidae	3											R	R	
Empididae	3													
Eriopterini	9								R					
Maoridiamesa species	3		R						R		R			
Molophilus species	5						R			R				C
Muscidae	3			R		R				R				
Orthocladiinae	2	A	C	C	A	R		R	A	A	A	R		
Polypedilum species	3		R											R
Tanypodinae	5		R	C						R				R
Tanytarsini	3								A	A	R	R		
Zelandotipula species	6											R		
EPHEMEROPTERA														
Austroclima species	9	A				R	R	R					R	C
Coloburiscus humeralis	9													
Deleatidium species	8	VVA	VVA	VVA	VVA	VVA	VVA	VVA	VVA	VVA	VVA	VVA	VVA	VVA
Nesameletus species	9	R	R		R									

Table 17 ***Continued. Macroinvertebrate community composition of the Manuherikia River at Galloway in 2019/20. Data courtesy of Otago Regional Council. Only taxa that were abundant on at least one occasion are shown.***

TAXON	MCI score	Manuherikia River at Galloway												
		18/02/2019	18/03/2019	15/04/2019	20/05/2019	12/06/2019	8/07/2019	12/08/2019	3/10/2019	31/10/2019	25/11/2019	17/12/2019	22/01/2020	27/02/20
MEGALOPTERA														
Archichauliodes diversus	7	C	R		R	R			R	R		R		C
MOLLUSCA														
Physa / Physella species	3	R	C	C	A	R	R							
Potamopyrgus antipodarum	4	A	VA	A	VA	A	A	C	R	C	C	VA	A	VA
NEMATODA	3													
NEMERTEA	3		C											C
OLIGOCHAETA	1	C	C	R		R	R	R	R	C	C	C	C	A
PLATYHELMINTHES	3		A				R					R	R	C
PLECOPTERA														
Zelandobius species	5		C	A	A	A	A	R	A	A	R			
TRICHOPTERA														
Costachorema species	7			R	R	R		R						
Hudsonema amabile	6	C	C	R	C	R	R	R		R				C
Hydrobiosidae early instar	5													R
Hydrobiosis species	5	A	A	A	A	A	A	C	C	A	C	A	A	C
Hydropsyche - Aoteapsyche gp	4	VVA	A	VA	VA	VA	A	VA	A	A	C	VVA	VVA	VA
Neurochorema species	6													
Olinga species	9		R	C	C	R		R		R	R			R
Oxyethira albiceps	2		C		R				R					
Plectrocnemia maclachlani	8												R	
Psilochorema species	8	A	R	C	A	C	C	C	C	C	C	A	A	C
Pycnocentria species	7	A	A	C	A	R	R		R	C			R	VA
Pycnocentrodes species	5	A	VA	A	C	C	C		C	A	A	A	R	

Table 17 Continued. Macroinvertebrate community composition of the Manuherikia River at Galloway in 2019/20. Data courtesy of Otago Regional Council. Only taxa that were abundant on at least one occasion are shown.

Number of taxa		19	24	20	19	20	17	14	17	21	15	15	14	21
Number of EPT taxa		9	11	10	12	11	9	9	8	9	7	5	8	9
% EPT taxa		47	46	50	63	55	53	64	47	43	47	33	57	43
MCI score		105	93	97	108	105	100	110	96	101	95	91	106	97
SQMCI score		5.7	6.6	6.4	6.1	6.9	7.3	7.2	7.2	7.0	7.3	5.6	6.0	7.0

5.3.7. Macroinvertebrate indices

ASPM

The average score per metric (ASPM), macroinvertebrate community index calculated for the Manuherikia at Blackstone Hill, Ophir and Galloway sites are compared to the macroinvertebrate attribute tables in the NOF (Tables 14 and 15 of the NOF) in Figure 26. Over the period 2016-2020, the median ASPM was 0.55 (B-band) at the Blackstone Hill site, 0.56 (B-band) at Ophir and 0.57 (B-band) at the Galloway site (Figure 26). ASPM scores in the B-band indicate macroinvertebrate communities that have *"mild to moderate loss of ecological integrity"*.

Macroinvertebrate Community Index

The median MCI for the period 2016-2020 was 98 (C-band) at Blackstone Hill, 110 (B-band) at Ophir and 108.6 (C-band) at Galloway (Figure 27). The NOF narrative for the various bands suggests that the MCI in the C-band indicates *"moderate organic pollution or nutrient enrichment"*, although this is not borne out by the water quality data for the Blackstone site (see Section 5.1.2), and the low MCI score at this site is likely to reflect the dominance of the periphyton community at this site by Didymo (see Section 5.2.1). MCI scores in B-band (≥110 and <130 MCI units) indicate a "*Macroinvertebrate community indicative of mild organic pollution or nutrient enrichment. Largely composed of taxa sensitive and insensitive to organic pollution/nutrient enrichment."*.

Semi-Quantitative Macroinvertebrate Community Index

The median SQMCI for the period 2016-2020 was 5.51 (B-band) at Blackstone Hill, 5.75 (B-band) at Ophir and 6.54 (A-band) at Galloway (Figure 28). The NOF narrative for the various bands suggests that the SQMCI in the B-band indicates a "*Macroinvertebrate community indicative of mild organic pollution or nutrient enrichment. Largely composed of taxa sensitive and insensitive to organic pollution/nutrient enrichment."*.

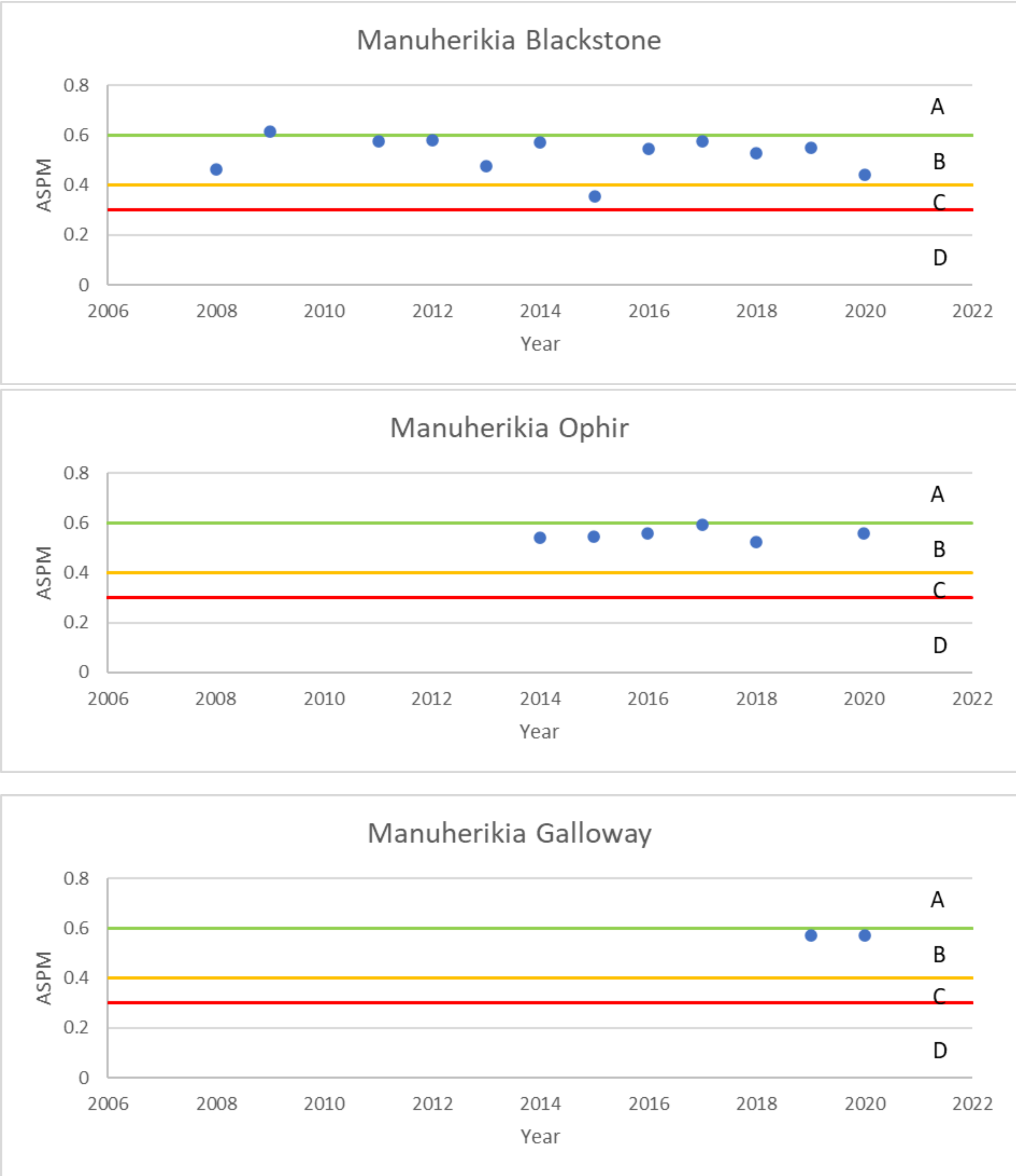

Figure 26 ***Average Score Per Metric scores for long-term monitoring sites in the Manuherikia mainstem. Data courtesy of the ORC.***

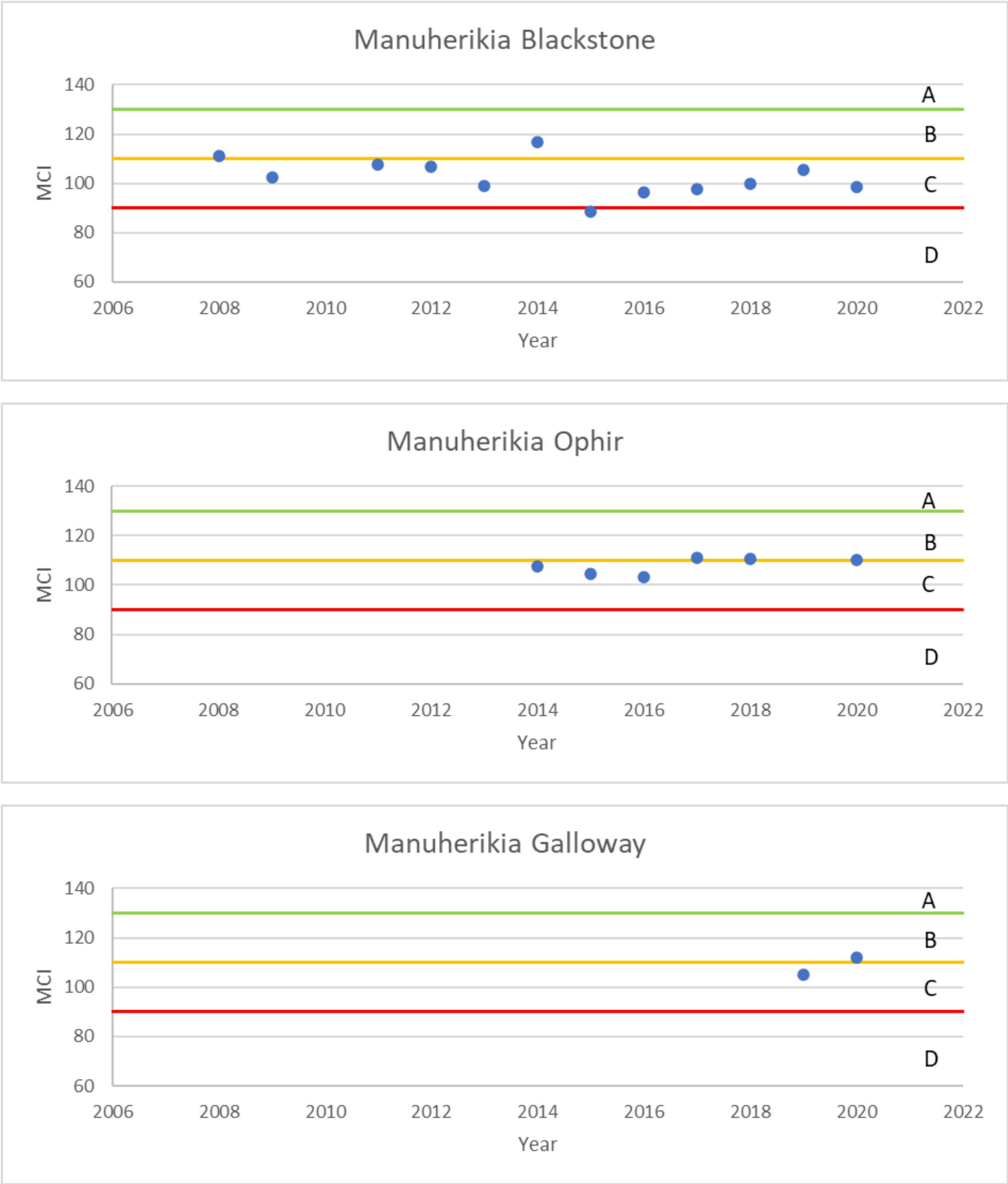

Figure 27 ***Macroinvertebrate Community Index (MCI) for long-term monitoring sites in the Manuherikia mainstem. Data courtesy of the ORC.***

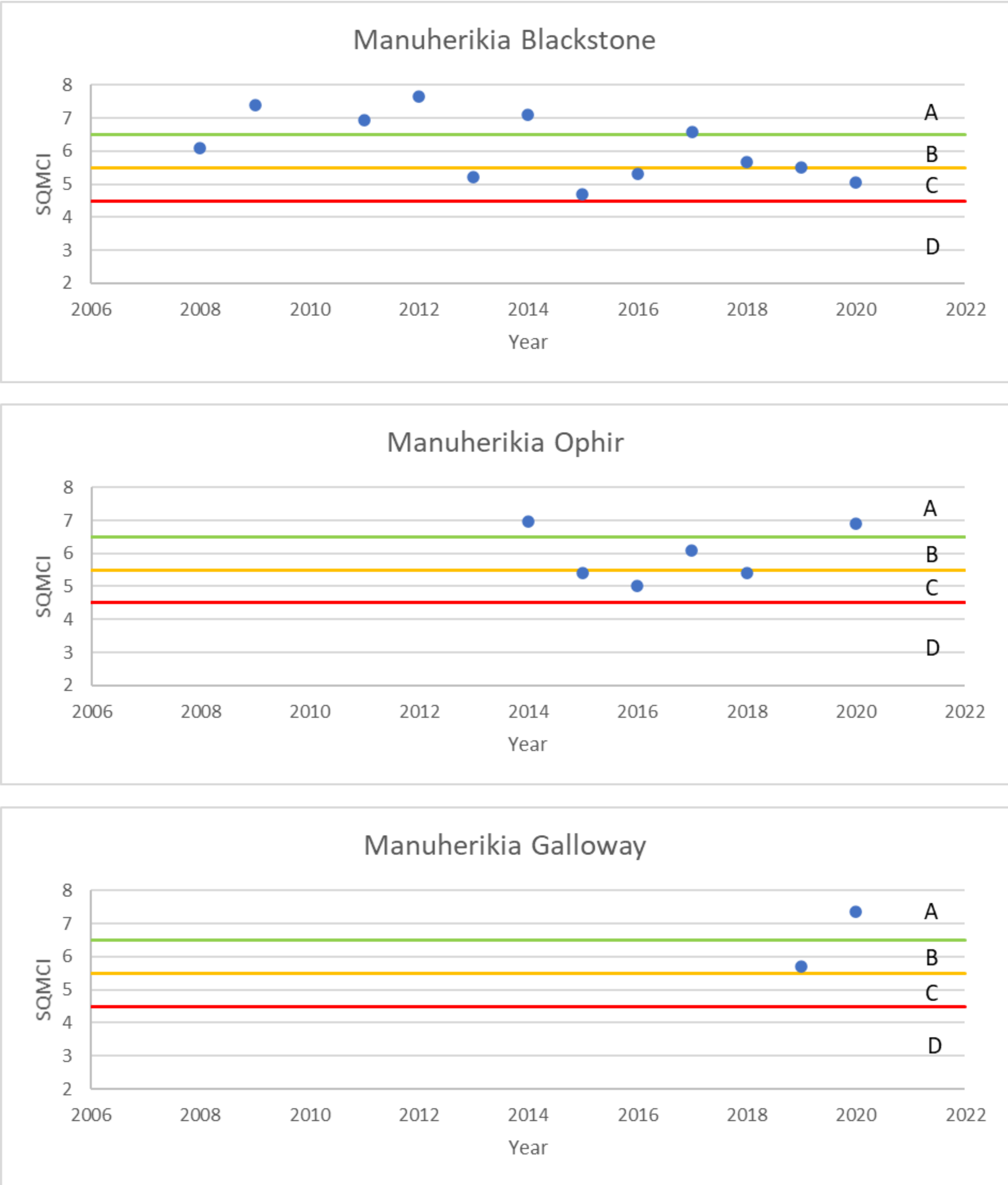

Figure 28 ***Semi-quantitative macroinvertebrate community index (SQMCI) for long-term monitoring sites in the Manuherikia mainstem. Data courtesy of the Otago Regional Council.***

5.3.8. Macroinvertebrate summary

The macroinvertebrate community at all sites in the Manuherikia River have been dominated by the common mayfly *Deleatidium* on most occasions, with the net-spinning caddis fly *Hydropsyche,* the mudsnail *Potamopyrgus antipodarum*, riffle beetles (Elmidae) and the cased caddis *Pycnocentrodes* also among the most abundant taxa collected.

Macroinvertebrate indices (ASPM, MCI, SQMCI) for sites in the mainstem of the Manuherikia River for the period 2016-2020 are generally consistent with mild organic pollution and/or organic enrichment.

The lowest MCI scores were observed at the Blackstone Hill monitoring site, where the water quality is highest (Section 5.1), most likely due to the abundance of the invasive diatom Didymo at this site (Section 5.2). This highlights the potential negative impacts of the introduced diatom if it were to become more prevalent downstream as a result of reductions in DRP expected as areas of flood irrigation are converted to spray irrigation.

6. Fish

Eight freshwater fish species have been recorded from the mainstem of the Manuherikia River downstream of Falls Dam (Table 18). Native fish recorded from the mainstem include lamprey, longfin eel, Central Otago roundhead galaxias, kōaro and upland bully (Table 18), although most of these species have been recorded on few occasions and/or locations, with upland bully being the only native species that is widespread and commonly encountered (Figure 29). Central Otago roundhead galaxias are classified as “nationally endangered”, while lamprey are classified as “nationally vulnerable” (Dunn *et al.* 2018). Longfin eels and kōaro are listed as “at risk, declining” (Dunn *et al.* 2018).

Brown trout are widely distributed throughout the mainstem while rainbow trout have been recorded from the lower river and perch have been recorded from the mainstem near the Chatto Creek confluence (Figure 29).

Only brown trout and upland bully have been recorded from the mainstem of the Manuherikia River between Falls Dam and Ophir (NZ Freshwater Fish Database, downloaded 15 July 2020).

Table 18 ***Fish species recorded from the mainstem of the Manuherikia River. Threat status based on Dunn* et al. *(2018).***

Common name	Species	Source	Threat status
Longfin eel	*Anguilla dieffenbachia*	NZFFDB	Declining
Central Otago Roundhead galaxias	*Galaxias anomolus*	NZFFDB	Nationally endangered
Kōaro	*Galaxias brevipinnis*	NZFFDB	Declining
Upland bully	*Gobiomorphus brevipinnis*	NZFFDB	Not threatened
Lamprey	*Geotria australis*	NZFFDB	Nationally vulnerable
Brown trout	*Salmo trutta*	NZFFDB	Introduced & naturalised
Rainbow trout	*Oncorhynchus mykiss*	NZFFDB	Introduced & naturalised
Perch	*Perca fluviatilis*	NZFFDB	Introduced & naturalised

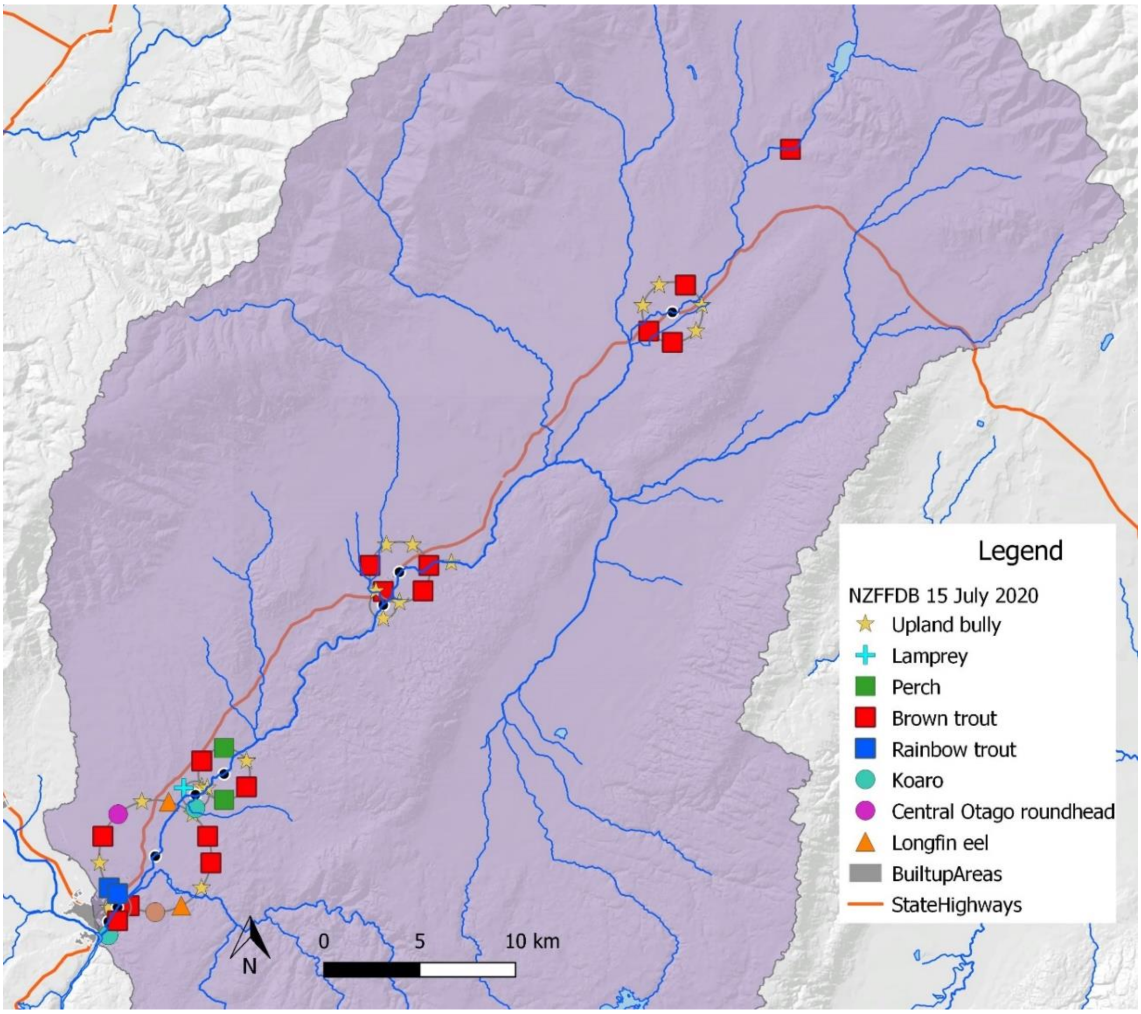

Figure 29 ***Distribution of introduced fish species in the mainstem of the Manuherikia River based on the NZ Freshwater Fish Database (NZFFDB, downloaded 15 July 2020)***

The Manuherikia River supports a regionally important brown trout fishery (Otago Fish & Game Council, 2015). Table 13 presents angler effort on the Manuherikia River, recorded during National Angler Surveys conducted in 1994/95, 2001/2002, 2007/08 and 2014/15 (Table 19).

Table 19 Angler effort on the Manuherikia River and Dunstan Creek (angler days ± standard error), based on the national angler survey (Unwin, 2016).

Angler usage (angler days ± SE)			
1994/95	2001/02	2007/08	2014/15
3,570 ± 840	5,630 ± 2,060	2,070 ± 650	2,140 ± 830

7. Assessment of ecological risk due to low flows

To help focus management or mitigation options an audit of the current practices and flow management was undertaken to try to determine if there were specific reaches of the Manuherikia River that are at risk due to low flows. This was done through checking flow and take record, visual inspection during the irrigation season, specifically holding the Falls Dam outflows and river flows at targeted levels and discussions with scheme owners and operators.

Our assessment led us to determine that there are five key reaches along the mainstem of the Manuherikia that have an increased risk to ecological values based on the current flow management regime. These five reaches are documented in Table 20.

Table 20. Reaches with elevated ecological risk based on the existing flow management regime.

Reach	Length of Reach (km)	Time of highest risk	Reach Specific Mitigation option
Falls Dam to Dunstan Creek confluence.	21	During filling Falls Dam, when BIC and OAIC are not taking, most likely May to June.	Residual flow at dam.
OAIC weir to Dunstan Creek confluence	4	When Falls Dam is below crest level and Dunstan Creek is flowing well, most likely September to October or following rain.	Residual flow past OAIC weir and Minimum flow at Campground
MICS intake to Clutha Creek confluence	24	Normally during summer low flows	Minimum flow at Campground and/or residual flow at the intake
GIS intake to bywash discharge	1.5	Normally during summer low flows	Minimum flow at Campground and/or residual flow at the intake
GIS intake to Clutha confluence	12	Normally during summer low flows	Minimum flow at Campground

Table 20 shows that two (Falls Dam and OAIC Weir) of the five high risk times for ecological values don't occur during the main irrigation season and therefore are not likely to be adequately protected by "minimum flow" conditions. Our understanding that low flows below Falls Dam and the OAIC weir occur relatively infrequently and generally for relatively short periods of time.

For the reach between the OAIC intake and Dunstan Creek it is also apparent from this investigation that consideration of both the severity of low flow, timing of the low flow and the duration of the low flow is important. This is because using stored water early in the season to increase flows at this point has the potential to compromise the benefit of using that same stored water later to maintain higher flows during the main irrigation season which complicates decisions when considering ecological risk.

7.1. Habitat modelling

Habitat modelling has been carried out at three location along the Manuherikia mainstem by NIWA and Waterways Consulting on behalf of ORC. These sites are at Blackstone hill, Ophir and Galloway. Below we present the results derived from these reaches for fish, macroinvertebrates and periphyton. Unless identified the fish habitat curves used in the modelling are all from Jowett and Richardson (2008)[39].

7.1.1. Upper Manuherikia at Blackstone Hill

Duncan & Bind (2016) have undertaken instream habitat modelling in the upper reaches of the Manuherikia at Blackstone between the BIC and OAIC intakes. We present habitat modelling results for the Blackstone reach against the natural 7-day MALF previously reported by ORC[40] although there are a number of consented takes upstream of the BIC take consent beyond 2040.

It is important to keep in mind that habitat modelling does not take a number of other factors into consideration, including the disturbance and mortality caused by flooding, physical barriers to the presence of a species and biological interactions (such as predation), which can have a significant influence on the distribution of aquatic species.

Brown trout and upland bully are the only two species that have been recorded from the Manuherikia downstream of Falls Dam (Section 6), although rainbow trout and longfin eels are also likely to be present. Of the species consistently recorded in the Manuherikia between Falls Dam and the Dunstan Creek confluence, brown and rainbow trout have the highest flow requirement (Table 22), whilst upland bully are expected to have the lowest optimum flows (Table 21).

[39] Jowett, I.G. and Richardson, J. (2008). Habitat use by New Zealand Fish and Habitat Suitability Models. NIWA Science and Technology Series No 55. 148p.

[40] Olsen *et al.* (2017). Management flows for aquatic ecosystems in the Manuherikia River and Dunstan Creek. Otago Regional Council, Dunedin. 78 p. plus appendices.

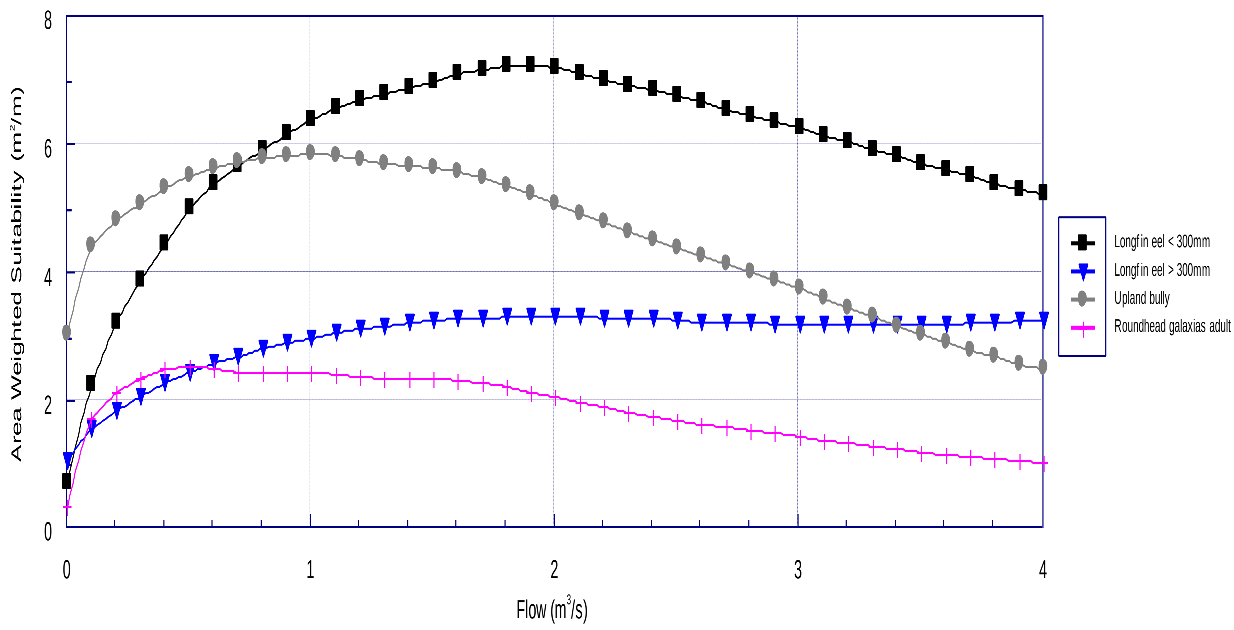

Figure 30. Relationship between reach area weighted suitability for native fish (AWS, a measure of potential habitat) and flow in the Manuherikia River at Blackstone.

Table 21 Flows (m^3/s) that provide various levels of habitat retention levels for native fish relative to the naturalised 7-d MALF of 1.779 m^3/s.

Species Life Stage	Maximum Habitat (m^3/s)	90% (m^3/s)	80% (m^3/s)	70% (m^3/s)	60% (m^3/s)
Longfin eel >300mm	1.920	0.996	0.658	0.428	0.268
Longfin eel <300mm	1.840	1.069	0.749	0.512	0.383
Upland bully	0.960	0.208	0.088	0.036	0.010
Roundhead galaxias	0.480	0.172	0.122	0.073	0.044

Longfin eel

The analysis of Duncan & Bind (2016) predicts that habitat for adult longfin eel increased as flow increases to approximately 1.5 m^3/s, but was relatively stable at flows above this (Figure 30). However, habitat is also not currently the main factor affecting the distribution and abundance of longfin eels in the Manuherikia catchment. Recruitment of longfin eels in the Manuherikia catchment is low due to the presence of Roxburgh Dam, which blocks the inward migration of juvenile eels that have entered the Clutha/Mata-Au from the ocean. Historically, some of the elvers entering the Clutha/Mata-Au would have migrated up past Roxburgh into the Manuherikia catchment and beyond.

Upland bully

The instream habitat model of Duncan & Bind (2016) predicts that a flow of 960 l/s would be optimum for upland bully (Figure 30).

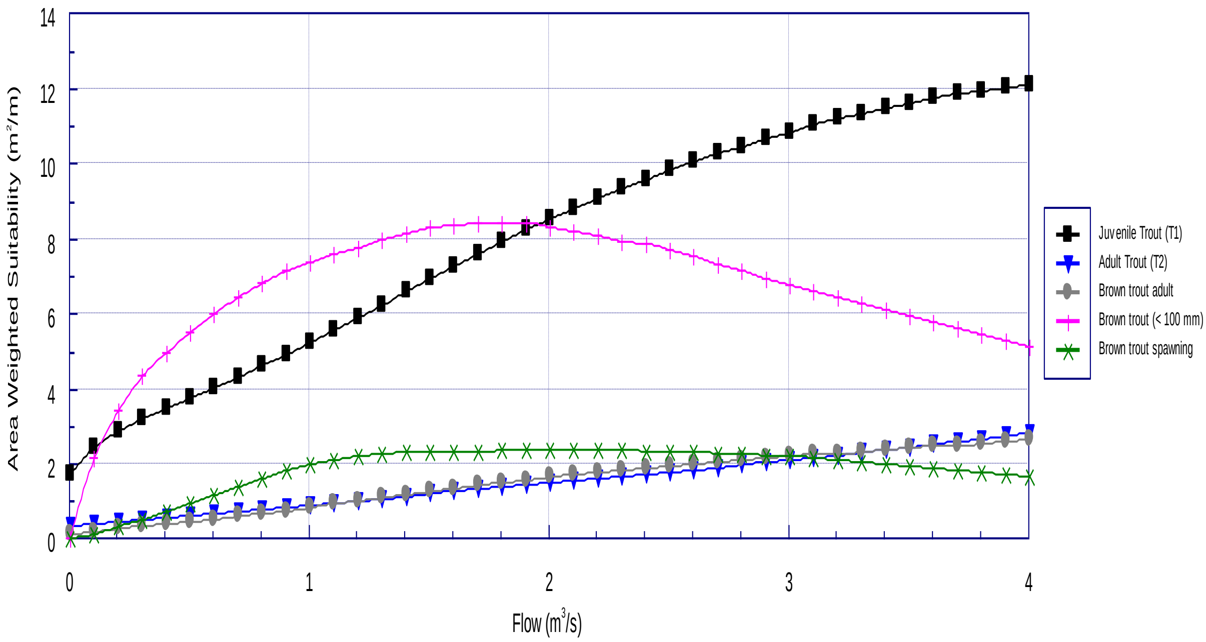

Figure 31. Relationship between reach area weighted suitability for brown and rainbow trout (RAWS, a measure of potential habitat) and flow in the Manuherikia River at Blackstone.

Table 22. Flows (m³/s) that provide various levels of habitat retention levels for brown trout relative to the naturalised 7-d MALF of 1.779 m3/s.

Species Life Stage	Maximum Habitat	90%	80%	70%	60%
Brown trout adult[1]	>4.000	1.594	1.421	1.246	1.070
Adult trout (T2)[2]	>4.000	1.546	1.312	1.073	0.831
Juvenile brown trout	1.760	1.107	0.782	0.581	0.419
Juvenile trout (T1)[2]	>4.000	1.541	1.314	1.085	0.841
Brown trout spawning[3]	2.040	1.130	0.938	0.816	0.705

[1] Hayes and Jowett (1994).

[2] Appendix 2 in Wilding, T.K. (2012). Regional methods for evaluating the effects of flow alteration on stream ecosystems. PhD thesis, Colorado State University.

[3] Shirvell and Dungey (1983).

Brown and rainbow trout

The instream habitat model of Duncan & Bind (2016) predicts that habitat for adult brown and rainbow trout will increase across the flow range modelled (i.e. the optimum flow is >4 m^3/s) (Figure 31). Habitat for brown trout spawning increased to an optimum at 2 m^3/s before declining as flows increased (Figure 31).

In the recent Lindis Environment Court Decision[41] it was found that comparing trout habitat to existing flows was a suitable baseline for an assessment of effects[42]. Our analysis and discussions with the Omakau Race Manager has found that on rare occasions the flow below the OAIC main race can be as low as 0.300 m^3/s when flows from Dunstan Creek are strong and the Falls Dam is below its crest level.

Habitat retention values have been provided as percentages compared to habitat at the current low flows of 0.3 m^3/s below the OAIC intake for completeness (Table 23).

Table 23. Predicted change in habitat retention levels that flows of 0.5 m^3/s, 0.7 m^3/s and 0.9 m^3/s provide relative to the observed low flows of 0.3 m^3/s below the OAIC intake.

Species/life stage	Habitat retention (%) at 0.5 m^3/s relative to 0.3 m^3/s	Habitat retention (%) at 0.7 m^3/s relative to 0.3 m^3/s	Habitat retention (%) at 0.9 m^3/s relative to 0.3 m^3/s
Adult trout (T2)[2]	122	143	165
Brown trout adult[1]	142	189	239
Juvenile trout (T1)[2]	118	135	154
Brown trout (<100mm)	127	145	165

[1] Hayes and Jowett (1994).

[2] Appendix 2 in Wilding, T.K. (2012). Regional methods for evaluating the effects of flow alteration on stream ecosystems. PhD thesis, Colorado State University.

7.1.2. Macroinvertebrate habitat modelling

Habitat for macroinvertebrates was assessed by modelling the effects of flow on a measure of general macroinvertebrate habitat (Food Producing) and habitat for three common macroinvertebrate taxa: the net-spinning caddis fly *Hydropsyche*[43], the common mayfly *Deleatidium*, and the sandy-cased caddis fly *Pycnocentrodes.*

Based on the analysis presented in Figure 32 and Table 24 the optimum flows for all macroinvertebrate taxa considered were well in excess of the estimated natural 7-day MALF: Food Producing (>4 m^3/s), *Aoteapsyche* (>4 m^3/s), *Pycnocentrodes* (>3 m^3/s), and *Deleatidium* (>3 m^3/s) (Figure 32 and Table 24).

Deleatidium is among the most abundant macroinvertebrate taxa in the Manuherikia River (Section 5.3). Flows of more than 0.988 m^3/s and 0.727 m^3/s are predicted to retain 80% and 70% of the *Deleatidium* habitat at the natural MALF, respectively (Table 24). Whilst expected to be less common than *Deleatidium* in the Manuherikia, both *Aoteapsyche* and *Pycnocentrodes* are common (Section 5.3). Flows of 1.074 m^3/s and 0.843 m^3/s are predicted to retain 80% and 70% of habitat for

[41] LINDIS CATCHMENT GROUP INCORPORATED (ENV-2016-CHC-61) Vs OTAGO REGIONAL COUNCIL Decision No. [2019] NZEnvC 166.

[42] Para 207 of LINDIS CATCHMENT GROUP INCORPORATED (ENV-2016-CHC-61) Vs OTAGO REGIONAL COUNCIL Decision No. [2019] NZEnvC 166.

[43] This genus of net-spinning caddis fly has previously been referred to as *Aoteapsyche*, but recent taxonomic revision changed the genus to *Hydropsyche*. Because *Aoteapsyche* was the correct genus at the time the HSC were developed, they are referred to as the *Aotepsyche* HSC.

Pycnocentrodes, respectively, while flows of 1.176 m^3/s and 0.903 m^3/s are predicted to retain 80% and 70% of habitat for *Aoteapsyche*, respectively (Table 24).

Food producing habitat is predicted to rapidly increase with flow to the maximum modelled flow of 4 m^3/s, flows of 1.284 m^3/s and 1.102 m^3/s are predicted to retain 80% and 70% of food producing habitat, respectively (Table 24).

The food producing habitat HSC is based on the work of Waters (1976), which was conducted in the United States on moderate sized trout rivers. On inspection of the habitat suitability curves (HSC), it is apparent that these curves suggest that food production is greatest in areas of moderate water depth (0.2-0.8 m), velocity (0.64-0.85 m/s) with cobble substrate. It is generally preferable to apply HSC that have been developed locally on rivers of a comparable nature. Given the dominance of the invertebrate community in the Manuherikia by the mayfly *Deleatidium* (see Section 5.3) and the availability of locally-derived HSC for this and other abundant macroinvertebrate taxa, we suggest that these HSC should be given more weight than the Food Producing HSC.

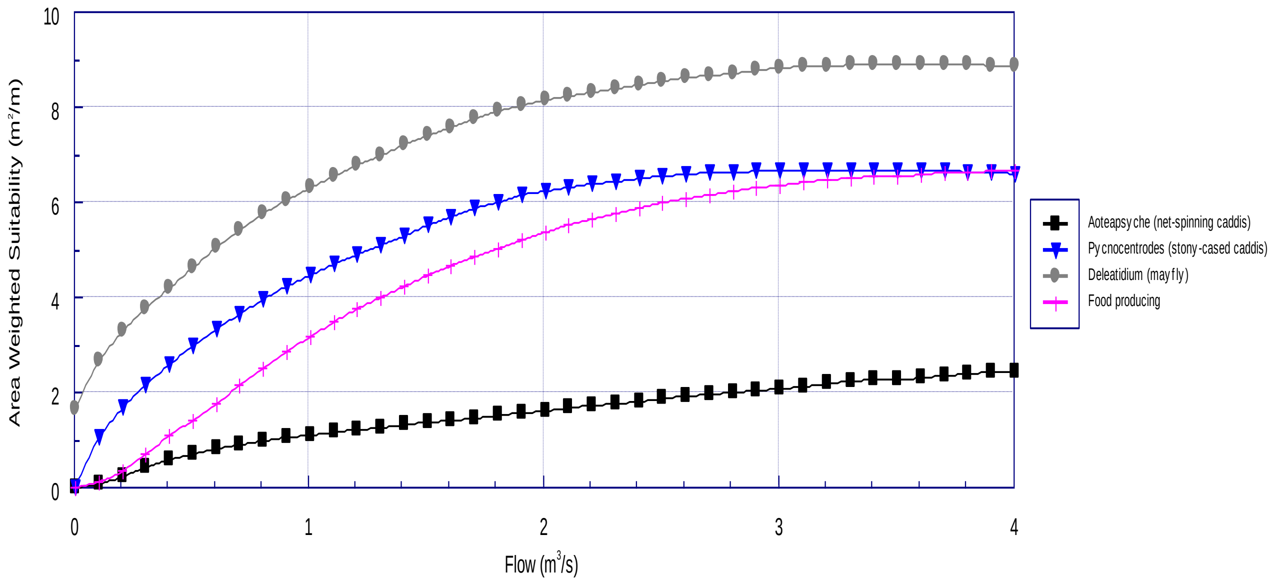

Figure 32 ***Habitat quality for invertebrate taxa at different flows in the upper Manuherikia River at Blackstone.***

Table 24. Flow requirements (m^3/s) for invertebrate habitat in the upper Manuherikia River relative to a naturalised 7-day MALF of 1.770 m3/s.

Species Life Stage	Maximum Habitat	90%	80%	70%	60%
Aoteapsyche	>4.0	1.472	1.176	0.903	0.699
Deleatidium	3.520	1.339	0.988	0.727	0.519
Pycnocentrodes	3.360	1.438	1.138	0.886	0.681
Food producing	>4.0	1.506	1.284	1.102	0.941

7.1.3. Periphyton habitat modelling

The average habitat quality for *Phomidium* and short filamentous algae increased with flow to 2 m³/s, but was relatively stable as flows increased above this level (Figure 33). The average habitat quality for long filamentous algae decreased with increasing flows, while the habitat quality for native diatoms increased across the modelled flow range (Figure 33).

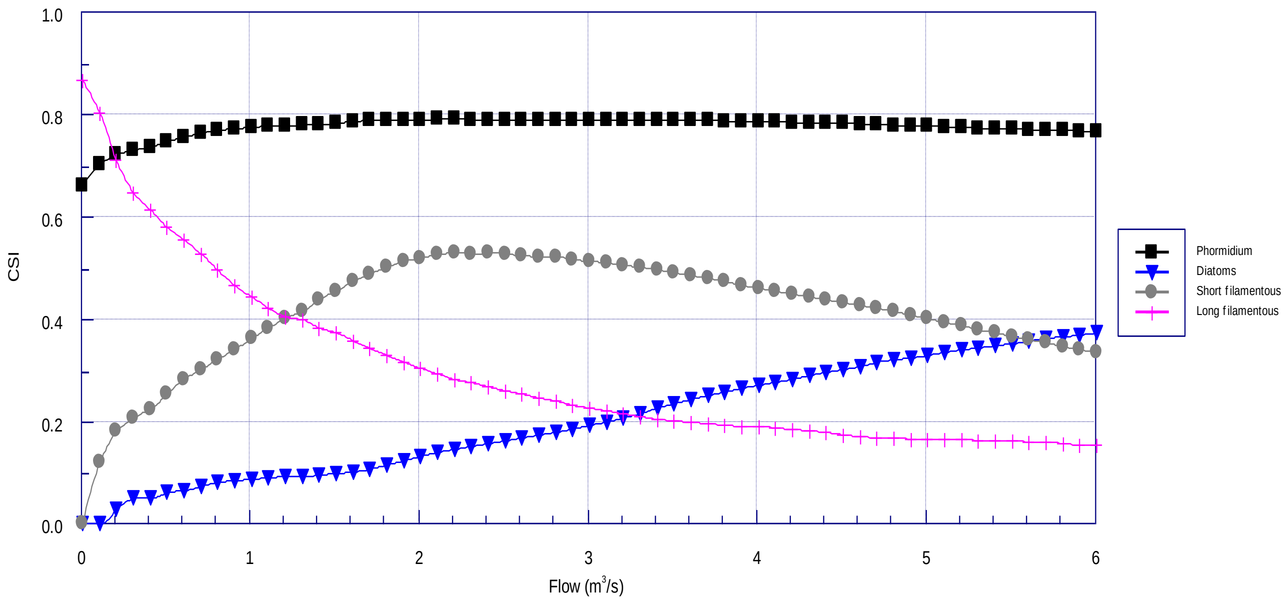

Figure 33. Habitat quality for different types of periphyton at different flows in the upper Manuherikia River at Blackstone.

Table 25. Flow requirements for periphyton habitat in the upper Manuherikia River at Blackstone. Flows that result in the given increase in habitat relative to naturalised 7-d MALF of 1.770 m³/s.

Species Life Stage	Maximum Habitat (m³/s)	Flow (m³/s) at which % habitat retention occurs			
		125	150	200	250
Phomidium	>6.0	-	-	-	-
Diatoms	>6.0	-	-	-	-
Short filamentous	2.7	-	-	-	-
Long filamentous	<0.05	1.150	0.800	0.300	0.05

Modelling of periphyton habitat suggests that for the most part across the natural low flow range increasing flow results in increases to habitat, with only long filamentous algae displaying a preference for very low flows (Figure 33). The risk of the proliferation of long filamentous algae at Blackstone is increased at flows of less than 0.800 m³/s (Table 25). However, this site is typically dominated by the invasive diatom Didymo (Section 5.2), which is expected to adversely affect the macroinvertebrate community at this site. Therefore, the predicted increase in the risk of long filamentous green algae proliferating in this reach is not expected to significantly affect the macroinvertebrate community present.

7.2. Habitat modelling – Mid Manuherikia at Ophir.

Waterways Consulting and ORC have undertaken instream habitat modelling for the Manuherikia at Ophir. We present habitat modelling results for the Ophir reach against the natural 7-day MALF previously reported by ORC.[44]

It is important to keep in mind that habitat modelling does not take a number of other factors into consideration, including the disturbance and mortality caused by flooding, physical barriers to the presence of a species and biological interactions (such as predation), which can have a significant influence on the distribution of aquatic species.

Brown trout, and upland bully have all been recorded in the vicinity of Ophir (Section 6). Of the species consistently recorded in the Manuherikia near Ophir, brown trout have the highest flow requirement (Figure 34), whilst upland bully are expected to have the lowest optimum flows (Figure 34).

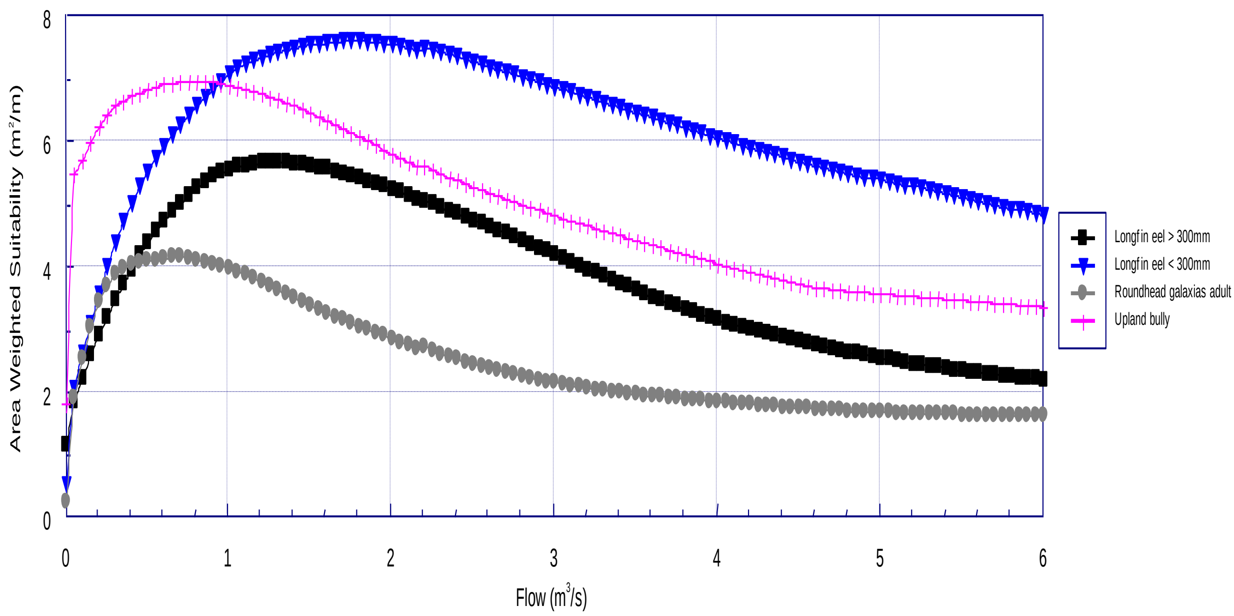

Figure 34. Relationship between reach area weighted suitability for native fish (AWS, a measure of potential habitat) and flow in the Manuherikia River at Ophir.

[44] Olsen *et al.* (2017). Management flows for aquatic ecosystems in the Manuherikia River and Dunstan Creek. Otago Regional Council, Dunedin. 78 p. plus appendices.

Table 26. Flows (m^3/s) that provide various levels of habitat retention levels for native fish relative to the naturalised 7-d MALF of 3.2 m^3/s.

Species Life Stage	Maximum Habitat	90%	80%	70%	60%
Longfin eel >300mm	1.260	0.318	0.246	0.180	0.121
Longfin eel <300mm	1.740	0.631	0.469	0.345	0.253
Upland bully	0.840	0.038	0.031	0.023	0.016
Roundhead galaxias	0.660	0.053	0.047	0.040	0.033

Longfin eel

The habitat model produced by ORC predicts that habitat for adult longfin eel increased as flow increases to approximately 1.260 m^3/s, before declining at flows above this (Figure 34). However, habitat is also not currently the main factor affecting the distribution and abundance of longfin eels in the Manuherikia catchment. Recruitment of longfin eels in the Manuherikia catchment is low due to the presence of Roxburgh Dam, which blocks the inward migration of juvenile eels that have entered the Clutha/Mata-Au from the ocean. Historically, some of the elvers entering the Clutha/Mata-Au would have migrated up past Roxburgh into the Manuherikia catchment and beyond. Even in the case that the upstream eel passage issues were able to be solved immediately, it would take many years of natural recruitment to the Clutha/Mata-Au catchment upstream of Roxburgh (likely longer than the maximum term of consent available) before habitat occupancy would be approaching the point where additional flow would be expected to have any effect on eel numbers/biomass in the Manuherikia catchment.

Upland bully and roundhead galaxias

ORCs instream habitat model for Ophir predicts that a flow of 840 l/s and 660 l/s would be optimum for upland bully and roundhead galaxias respectively (Figure 34 and Table 26).

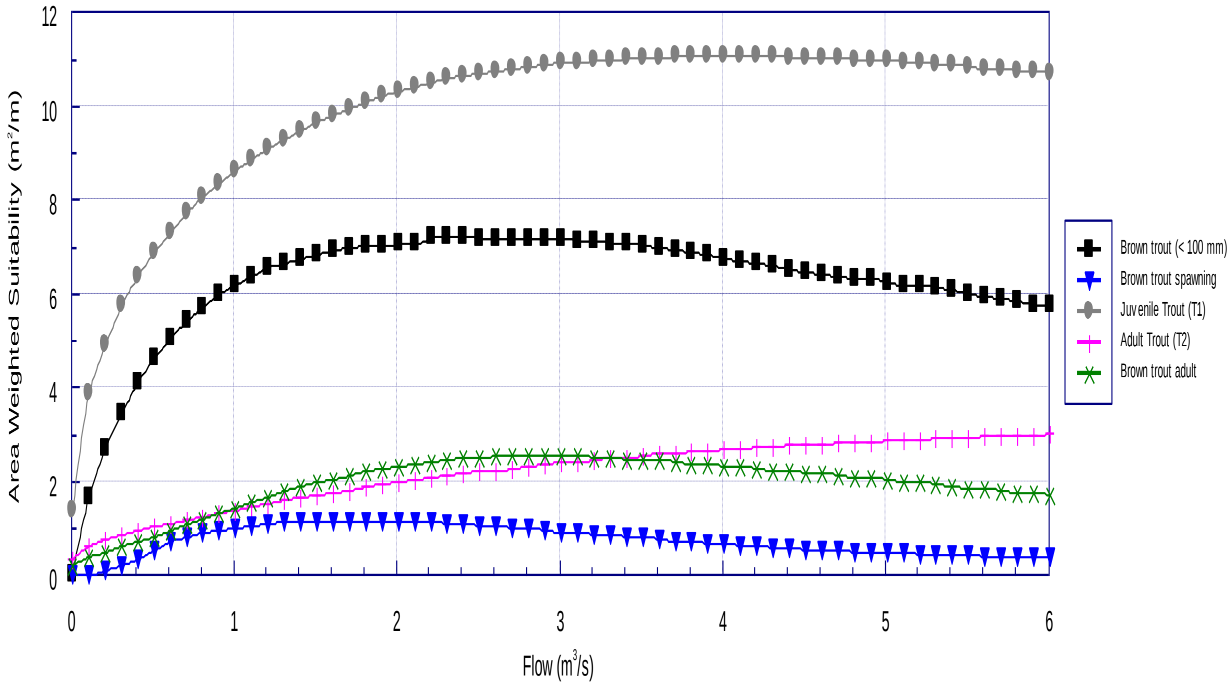

Figure 35. Relationship between reach area weighted suitability for brown and rainbow trout (RAWS, a measure of potential habitat) and flow in the Manuherikia River at Ophir.

Table 27. Flows (m^3/s) that provide various levels of habitat retention levels for brown trout relative to the naturalised 7-d MALF of 3.2 m^3/s.

Species Life Stage	Maximum Habitat	90%	80%	70%	60%
Brown trout adult[1]	2.820	1.898	1.553	1.287	1.071
Adult trout (T2)[2]	>6.0	2.530	1.988	1.529	1.127
Juvenile brown trout	2.160	1.110	0.795	0.584	0.432
Juvenile trout (T1)[2]	4.080	1.650	1.066	0.694	0.442
Brown trout spawning[3]	1.380	0.669	0.592	0.544	0.502

[1] Hayes and Jowett (1994).

[2] Appendix 2 in Wilding, T.K. (2012). Regional methods for evaluating the effects of flow alteration on stream ecosystems. PhD thesis, Colorado State University.

[3] Shirvell and Dungey (1983).

Brown and rainbow trout

ORCs instream habitat modelling for the Manuherikia at Ophir predicts that optimum habitat for adult brown trout is provided for by a flow of 2.8 m^3/s (Figure 35). Habitat for brown trout spawning increased to an optimum at 1.380 m^3/s before declining as flows increased (Figure 35).

7.2.1. Macroinvertebrate habitat modelling

Habitat for macroinvertebrates was assessed by modelling the effects of flow on a measure of general macroinvertebrate habitat (food producing) and habitat for three common macroinvertebrate taxa: the net-spinning caddis fly *Hydropsyche*, the common mayfly *Deleatidium*, and the sandy-cased caddis fly *Pycnocentrodes.*

Based on the analysis presented in Figure 36 and Table 28 the optimum flows for all macroinvertebrate taxa considered were well in excess of the estimated natural 7-day MALF: Food Producing (>3.5 m^3/s), *Aoteapsyche* (>6 m^3/s), *Pycnocentrodes* (>3 m^3/s), and *Deleatidium* (>5.5 m^3/s) (Figure 36 and Table 28).

Deleatidium is among the most abundant macroinvertebrate taxa in the Manuherikia River (Section 5.3). Flows of more than 1.293 m^3/s and 0.860 m^3/s are predicted to retain 80% and 70% of the *Deleatidium* habitat at the natural MALF, respectively (Table 28). Whilst expected to be less common than *Deleatidium* in the Manuherikia, both *Aoteapsyche* and *Pycnocentrodes* are common (Section 5.3). Flows of 1.311 m^3/s and 1.011 m^3/s are predicted to retain 80% and 70% of habitat for *Pycnocentrodes*, respectively, while flows of 2.644 m^3/s and 2.407 m^3/s are predicted to retain 80% and 70% of habitat for *Aoteapsyche*, respectively (Table 28).

Food producing habitat is predicted to rapidly increase with flow to 4 m^3/s, flows of 1.858 m^3/s and 1.536 m^3/s are predicted to retain 80% and 70% of food producing habitat, respectively (Table 28).

The food producing habitat HSC is based on the work of Waters (1976), which was conducted in the United States on moderate sized trout rivers. On inspection of the habitat suitability curves (HSC), it is apparent that these curves suggest that food production is greatest in areas of moderate water depth (0.2-0.8 m), velocity (0.64-0.85 m/s) with cobble substrate. It is generally preferable to apply HSC that have been developed locally on rivers of a comparable nature.

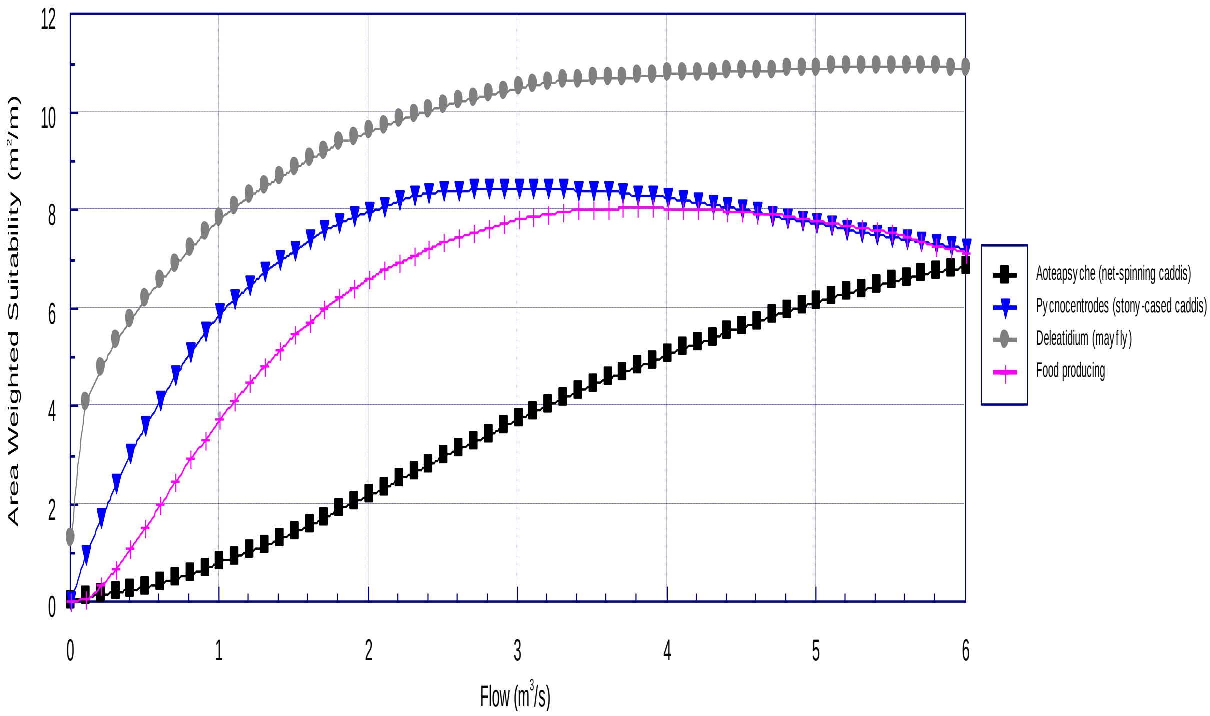

Figure 36. Habitat quality for invertebrate taxa at different flows in the Manuherikia River at Ophir.

Table 28. Flow requirements (m^3/s) for invertebrate habitat in the Manuherikia River at Ophir relative to a naturalised 7-day MALF of 3.2 m^3/s.

Species Life Stage	Maximum Habitat	90%	80%	70%	60%
Aoteapsyche	>6.0	2.928	2.664	2.407	2.149
Deleatidium	5.520	1.940	1.293	0.860	0.548
Pycnocentrodes	3.0	1.710	1.311	1.011	0.798
Food producing	3.780	2.335	1.858	1.536	1.279

7.2.2. Periphyton habitat modelling

The average habitat quality for short filamentous algae increased with flow to 3 m^3/s, before declining as flows increased above this level (Figure 37 and Figure 33). The average habitat quality for long filamentous algae decreased with increasing flows, while the habitat quality for native diatoms and *Phomidium* increased across the modelled flow range (Figure 37).

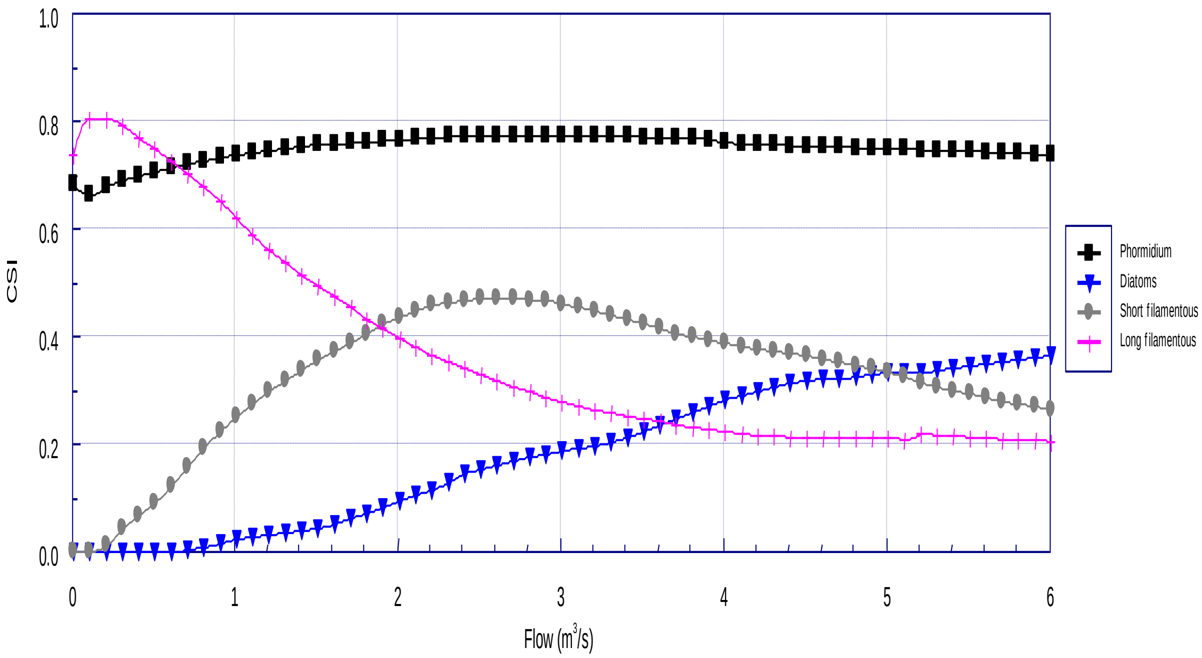

Figure 37. Habitat quality for different types of periphyton at different flows in the Manuherikia River at Ophir.

Table 29. Flow requirements for periphyton habitat in the lower Manuherikia River at Ophir. Flows that result in the given increase in habitat relative to naturalised 7-d MALF of 3.2 m^3/s.

Species Life Stage	Maximum Habitat (m^3/s)	Flow (m^3/s) at which % habitat retention occurs			
		125	150	200	250
Phomidium	>6.0	-	-	-	-
Diatoms	>6.0	-	-	-	-
Short filamentous	2.820	-	-	-	-
Long filamentous	0.480	2.5	2	1.3	0.850

Modelling of periphyton habitat suggests that across the modelled flow range up to 6 m^3/s as flows increase so does habitat for *Phomidium* and diatoms, while the same is true up to 3m^3/s for short filamentous algae (Figure 37). Only long filamentous algae displaying a preference for flows in the lower end of this range (Figure 37). The risk of the proliferation of long filamentous algae at Ophir is increased at flows of less than 2 m^3/s and is significantly elevated at flows of less than 1.3 m^3/s (Table 29). The existing minimum flow at Ophir (0.820 m^3/s) is expected to increase habitat quality for long filamentous algae by about 2.5 times compared to the naturalised 7-d MALF (Table 29).

7.2.3. Existing Minimum Flow at Ophir

Currently there is a minimum flow set at Ophir of 0.820 m^3/s. This flow is often criticised for being too low relative to the natural 7-day MALF of 3.2 m^3/s or that because this minimum flow is not reached frequently it is also too low.

Our understanding is that the minimum flow at Ophir would only be reached if Falls Dam was empty or close to empty, because there is a flow sharing arrangement between the four mainstem scheme takes meaning a proportion of flow from the upper catchment must pass to deliver water to the MICS and GIS intakes. This means that when assessing the Ophir minimum flow of 0.820 m^3/s it is important to do so in the context of when of how often it is reached and the hydrological situation facing the catchment.

Hydrological monitoring shows that a daily average flow of 0.820 m^3/s or less has only occurred <1% of the time since 1971, or for 186 days during this time. There has been no daily average flow less than 0.820 m^3/s since 1999, which is the last time Falls Dam was at its minimum operating level[45]. Since 1999 the lowest daily average flow at Ophir has been 1.021 m^3/s.

With the recent habitat modelling completed at Ophir by Waterways Consulting Ltd (Dr Richard Allibone) and ORC we are able to assess the expected levels of habitat protection a minimum flow of 0.820 m^3/s provides relative to the natural 7-day MALF and the observed 7-day MALF for key species and life stages (Table 30).

[45] Pers Comm. Roger Williams Falls Dam manager.

Table 30. Habitat protection provided by a minimum flow of 0.820 m³/s at Ophir as a percentage of the natural 7-day MALF of 3.2 m³/s and the observed 7-day MALF of 2.2 m³/s.

Species Life Stage	Level of habitat Protection Relative to Natural MALF (%)	Level of habitat Protection Relative to Observed MALF (%)
Large Longfin eel (>300mm)	133	104
Small Longfin eel (<300mm)	98	88
Upland bully	150	125
Deleatidium	68	73
Pycnocentrodes	60	62
Adult brown trout	47	49
Adult trout	51	60

When considering both the frequency and duration of the Manuherikia River being at a minimum flow of 0.820 m^3/s at Ophir and that the habitat protection levels shown in Table 30 are a worst case scenario that only occurs in naturally very low flow years there appears to be little evidence to support altering this flow from an ecological perspective.

Ultimately the imposition of a minimum flow at Campground that is applied to all primary water takes from the Manuherikia River would control flows at Ophir in all seasons except the most extreme, at which time the Ophir minimum flow is likely to be very important to maintain ecological values.

7.3. Habitat modelling – Lower Manuherikia at Galloway

Waterways Consulting and ORC have undertaken instream habitat modelling for the Manuherikia at Galloway. We present these habitat modelling results for the Galloway reach against the natural 7-day MALF previously reported by ORC.[46]

It is important to keep in mind that habitat modelling does not take a number of other factors into consideration, including the disturbance and mortality caused by flooding, physical barriers to the presence of a species and biological interactions (such as predation), which can have a significant influence on the distribution of aquatic species.

Brown trout, rainbow trout, longfin eel and upland bully have all been recorded in the vicinity of Galloway (Section 6). Of the species consistently recorded in the Manuherikia near Galloway, brown and rainbow trout have the highest flow requirement (Table 31), whilst upland bully are expected to have the lowest optimum flows (Table 31).

[46] Olsen *et al.* (2017). Management flows for aquatic ecosystems in the Manuherikia River and Dunstan Creek. Otago Regional Council, Dunedin. 78 p. plus appendices.

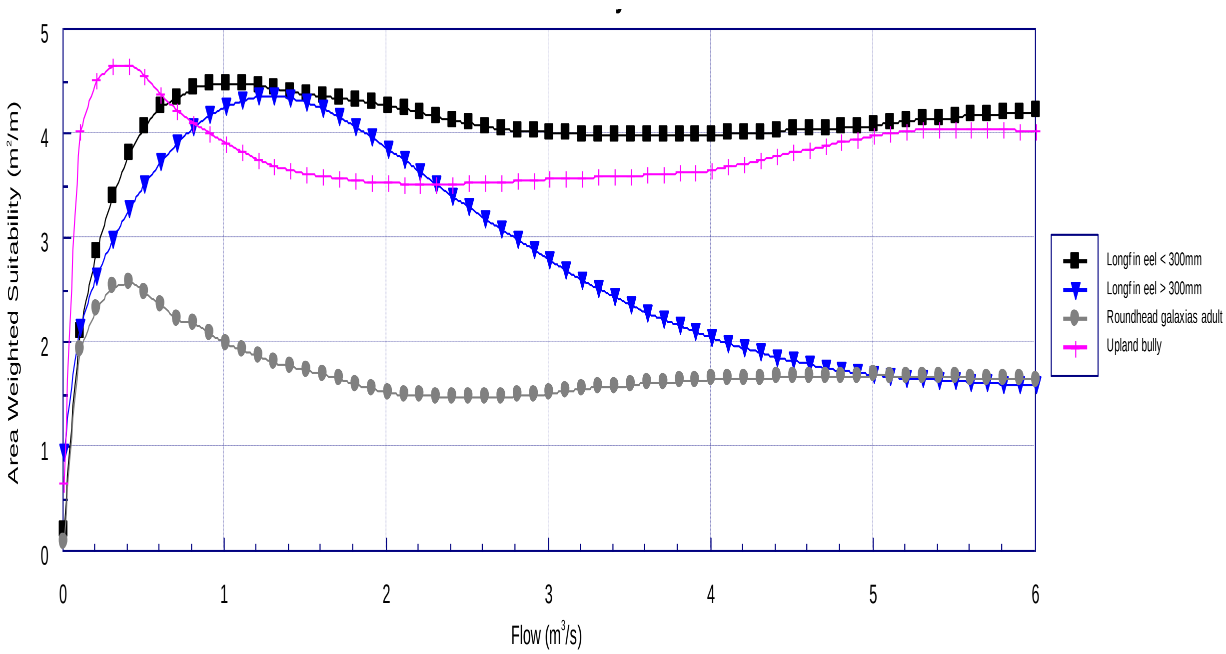

Figure 38. Relationship between reach area weighted suitability for native fish (AWS, a measure of potential habitat) and flow in the lower Manuherikia River at Galloway.

Table 31. Flows (m3/s) that provide various levels of habitat retention levels for native fish relative to the naturalised 7-d MALF of 3.9 m3/s in the lower Manuherikia River at Galloway.

Species Life Stage	Maximum Habitat	90%	80%	70%	60%
Longfin eel >300mm	1.260	0.066	0.049	0.035	0.021
Longfin eel <300mm	1.020	0.346	0.261	0.189	0.133
Upland bully	0.360	0.053	0.045	0.038	0.031
Roundhead galaxias	0.360	0.057	0.050	0.043	0.037

Longfin eel

The habitat model produced by ORC for Galloway predicts that habitat for adult longfin eel increased as flow increases to approximately 1.260 m^3/s, but was relatively stable at flows above this (Figure 38). However, habitat is also not currently the main factor affecting the distribution and abundance of longfin eels in the Manuherikia catchment. Recruitment of longfin eels in the Manuherikia catchment is low due to the presence of Roxburgh Dam, which blocks the inward migration of juvenile eels that have entered the Clutha/Mata-Au from the ocean. Historically, some of the elvers entering the Clutha/Mata-Au would have migrated up past Roxburgh into the Manuherikia catchment and beyond.

Upland bully and roundhead galaxias

ORCs instream habitat model for Galloway predicts that a flow of 0.360 m^3/s would be optimum for both upland bully and roundhead galaxias (Figure 38).

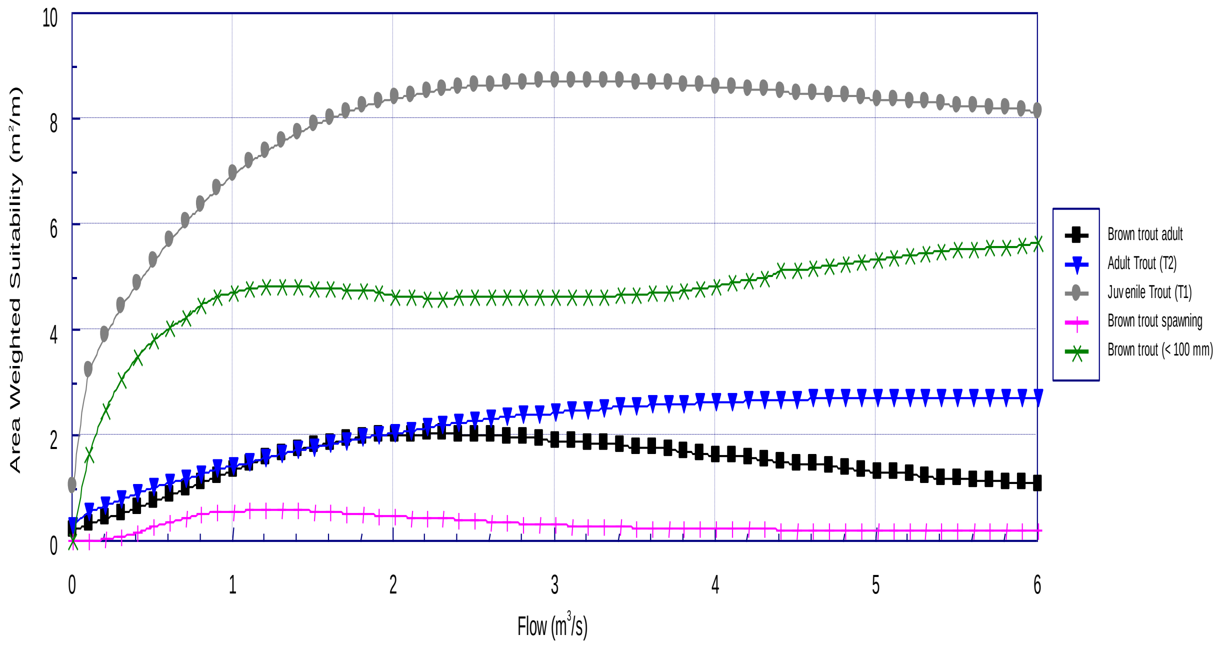

Figure 39. Relationship between reach area weighted suitability for brown and rainbow trout (RAWS, a measure of potential habitat) and flow in the lower Manuherikia River at Galloway.

Table 32. Flows (m³/s) that provide various levels of habitat retention levels for brown trout relative to the naturalised 7-d MALF of 3.9 m³/s in the lower Manuherikia River at Galloway.

Species Life Stage	Maximum Habitat	90%	80%	70%	60%
Brown trout adult[1]	2.220	1.132	0.976	0.838	0.709
Adult trout (T2)[2]	5.460	2.746	2.101	1.606	1.195
Juvenile brown trout	>6.000	0.736	0.514	0.366	0.266
Juvenile trout (T1)[2]	3.120	1.408	0.984	0.698	0.470
Brown trout spawning[3]	1.200	0.437	0.411	0.385	0.359

[1] Hayes and Jowett (1994).

[2] Appendix 2 in Wilding, T.K. (2012). Regional methods for evaluating the effects of flow alteration on stream ecosystems. PhD thesis, Colorado State University.

[3] Shirvell and Dungey (1983).

Brown and rainbow trout

The instream habitat model by Waterways Consulting and ORC predicts that habitat for adult brown based on the Jowett and Hayes curve peaks at 2.2 m³/s , while the Wilding curve which combines brown and rainbow trout preferences predicts optimum flows of ~5.5 m³/s for adult brown and rainbow trout (Figure 39). Habitat for brown trout spawning increased to an optimum at 1.2 m³/s before declining as flows increased (Figure 39).

In the recent Lindis Environment Court Decision[47] it was found that comparing trout habitat to existing flows was a suitable baseline for an assessment of effects[48]. Habitat retention values for a flow of 1.1 m^3/s have been provided as percentages compared to habitat at the observed low flows at the Campground flow site for completeness (Table 23).

Table 33. Predicted change in habitat retention levels relative to the observed daily minimum of 0.406 m^3/s, the observed average annual daily minimum of 0.698 m^3/s and the observed 7-day MALF of 0.911 m^3/s at ORC's Campground flow site.

Species/life stage	Habitat retention (%) at 1.100 m^3/s relative to 0.406 m^3/s	Habitat retention (%) at 1.100 m^3/s relative to 0.698 m^3/s	Habitat retention (%) at 1.100 m^3/s relative to 0.911 m^3/s
Adult trout (T2)[2]	165	127	111
Brown trout adult[1]	229	149	117
Juvenile trout (T1)[2]	146	119	108
Brown trout (<100mm)	136	113	104

[1] Hayes and Jowett (1994).

[2] Appendix 2 in Wilding, T.K. (2012). Regional methods for evaluating the effects of flow alteration on stream ecosystems. PhD thesis, Colorado State University.

7.3.1. Macroinvertebrate habitat modelling

Habitat for macroinvertebrates was assessed by modelling the effects of flow on a measure of general macroinvertebrate habitat (Food Producing) and habitat for three common macroinvertebrate taxa: the net-spinning caddis fly *Hydropsyche*[49], the common mayfly *Deleatidium*, and the sandy-cased caddis fly *Pycnocentrodes.*

Based on the analysis presented in Figure 40 and Table 34 the optimum flows for all macroinvertebrate taxa considered were well in excess of the estimated natural 7-day MALF: Food Producing (>4.5 m^3/s), *Aoteapsyche* (>6 m^3/s), *Pycnocentrodes* (>5.2 m^3/s), and *Deleatidium* (>6 m^3/s) (Figure 40 and Table 34).

Deleatidium is among the most abundant macroinvertebrate taxa in the Manuherikia River (Section 5.3). Flows of more than 1.350 m^3/s and 0.890 m^3/s are predicted to retain 80% and 70% of the *Deleatidium* habitat at the natural MALF, respectively (Table 34). Whilst expected to be less common than *Deleatidium* in the Manuherikia, both *Aoteapsyche* and *Pycnocentrodes* are common (Section 5.3). Flows of 1.240 m^3/s and 0.923 m^3/s are predicted to retain 80% and 70% of habitat for

[47] LINDIS CATCHMENT GROUP INCORPORATED (ENV-2016-CHC-61) Vs OTAGO REGIONAL COUNCIL Decision No. [2019] NZEnvC 166.

[48] Para 207 of LINDIS CATCHMENT GROUP INCORPORATED (ENV-2016-CHC-61) Vs OTAGO REGIONAL COUNCIL Decision No. [2019] NZEnvC 166.

[49] This genus of net-spinning caddis fly has previously been referred to as *Aoteapsyche*, but recent taxonomic revision changed the genus to *Hydropsyche*. Because *Aoteapsyche* was the correct genus at the time the HSC were developed, they are referred to as the *Aotepsyche* HSC.

Pycnocentrodes, respectively, while flows of 2.998m^3/s and 2.602 m^3/s are predicted to retain 80% and 70% of habitat for *Aoteapsyche*, respectively (Table 34).

Food producing habitat is predicted to rapidly increase with flow to 4.5 m^3/s, flows of 1.716 m^3/s and 1.271 m^3/s are predicted to retain 80% and 70% of food producing habitat, respectively (Table 34). The food producing habitat HSC is based on the work of Waters (1976), which was conducted in the United States on moderate sized trout rivers. On inspection of the habitat suitability curves (HSC), it is apparent that these curves suggest that food production is greatest in areas of moderate water depth (0.2-0.8 m), velocity (0.64-0.85 m/s) with cobble substrate. It is generally preferable to apply HSC that have been developed locally on rivers of a comparable nature.

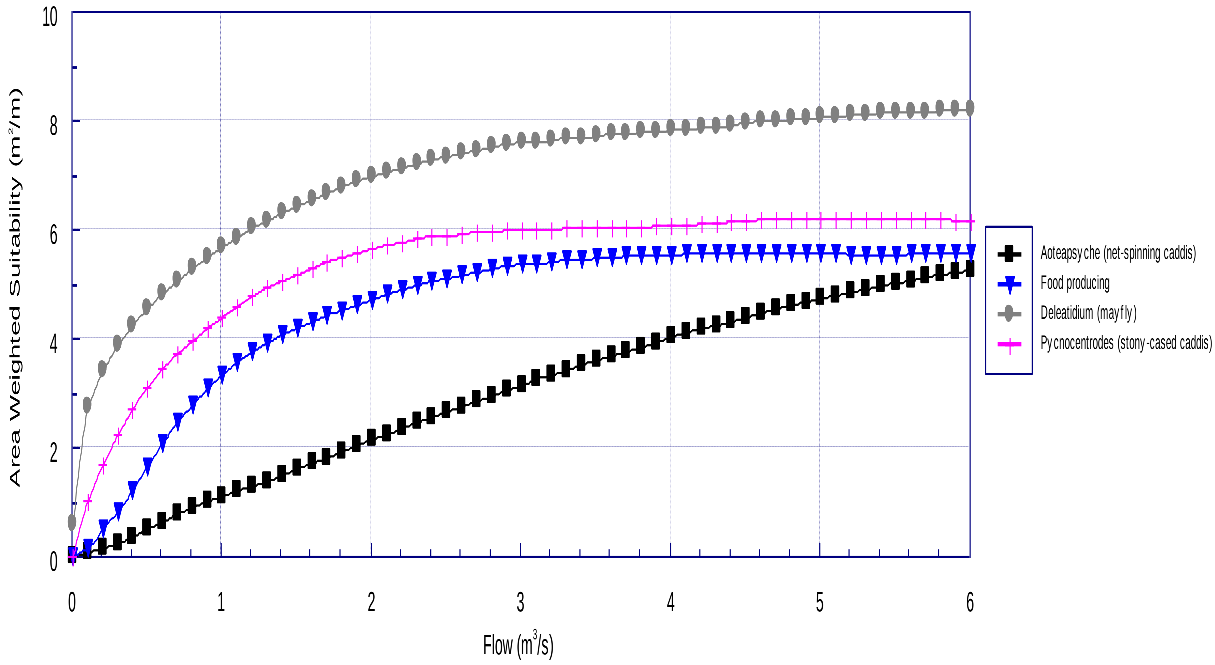

Figure 40 Habitat quality for invertebrate taxa at different flows in the Manuherikia River at Galloway.

Table 34. Flow requirements (m#/s) for invertebrate habitat in the Manuherikia River at Galloway relative to a naturalised 7-day MALF of 3.9 m#/s.

Species Life Stage	Maximum Habitat	90%	80%	70%	60%
Aoteapsyche	>6.0	3.435	2.998	2.602	2.208
Deleatidium	>6.0	2.057	1.357	0.890	0.554
Pycnocentrodes	5.220	1.754	1.241	0.923	0.671
Food producing	4.500	2.306	1.716	1.271	0.990

7.3.2. Periphyton habitat modelling

The average habitat quality for short filamentous algae increased with flow to 2 m^3/s, but was relatively stable as flows increased above this level (Figure 41). The average habitat quality for long filamentous algae decreased with increasing flows, while the habitat quality for native diatoms and *Phomidium* increased across the modelled flow range (Figure 41).

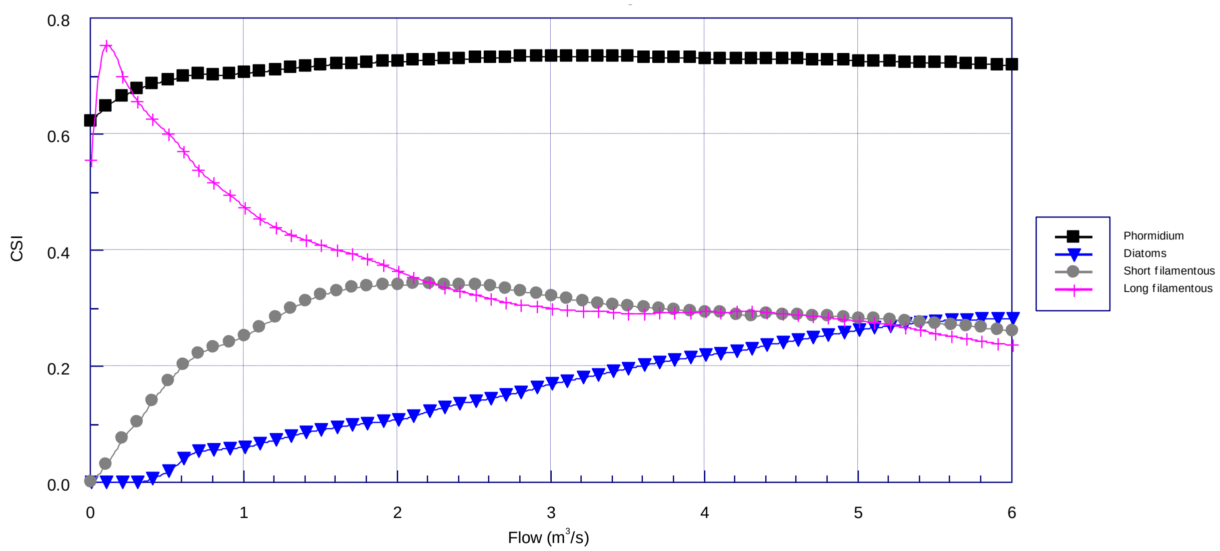

Figure 41. Variation in instream habitat quality (CSI) for different types of periphyton at different flows in the lower Manuherikia River at Galloway.

Table 35. Flow requirements for periphyton habitat in the lower Manuherikia River at Galloway. Flows that result in the given increase in habitat relative to naturalised 7-d MALF of 3.9 m^3/s.

Species Life Stage	Maximum Habitat (m^3/s)	Flow (m^3/s) at which % habitat retention occurs			
		125	150	200	250
Phomidium	>6.0	-	-	-	-
Diatoms	>6.0	-	-	-	-
Short filamentous	2.640	-	-	-	-
Long filamentous	0.180	1.950	1.150	0.550	0.150

Modelling of periphyton habitat suggests that across the modelled flow range of 0 – 6.0 m^3/s that for the most part increasing flow increases habitat, with only long filamentous algae displaying a clear preference for very low flows (Figure 41). The risk of the proliferation of long filamentous algae at Galloway is increased at flows of less than 1.150 m^3/s and is significantly elevated at flows of less than 0.550 m^3/s (Table 29).

8. NPSFM (2020) Compulsory Values

The NPSFM includes compulsory values for the following attributes ecosystem health, threatened species and mahinga kai.

Specifically, ecosystem health consists of five biophysical components: water quality, water quantity, habitat, aquatic life, and ecological processes. In a healthy freshwater ecosystem, all five biophysical components are suitable to sustain the indigenous aquatic life expected in the absence of human disturbance or alteration (before providing for other values). However, the NPSFM (2020) does not provide guidance on how the influence of introduced sports fish on indigenous aquatic life and ecological processes should be assessed. Simply, introduced sports fish alter indigenous ecosystem processes and indigenous aquatic life[50].

The Threatened Species compulsory value directs to the extent to which an FMU or part of an FMU that supports a population of threatened species has the critical habitats and conditions necessary to support the presence, abundance, survival, and recovery of the threatened species. All the components of ecosystem health must be managed, as well as (if appropriate) specialised habitat or conditions needed for only part of the life cycle of the threatened species. Again, this compulsory value has no guidance on implementation when the key threat to the survival and recovery of the threatened species is an introduced sports fish, as is the case for the Manuherikia River.

Mahinga Kai Value directs that kai would be safe to harvest and eat. Transfer of knowledge is able to occur about the preparation, storage and cooking of kai. In FMUs or parts of FMUs that are used for providing mahinga kai, the desired species are plentiful enough for long-term harvest and the range of desired species is present across all life stages. In the case of Manuherikia River, longfin eel a highly valued mahinga kai species, is unlikely to meet the requirements of this compulsory value due to recruitment issues caused by the presence of Roxburgh Dam, which blocks the inward migration of juvenile eels that have entered the Clutha/Mata-Au from the ocean.

8.1. Management objectives

Because of the complexities highlighted above with the compulsory values of the NPSFM (2020) for the Manuherikia River the focus of this report is on water quantity aspects of the ecosystem health attribute and the flow needs of threatened fish and traditional mahinga kai species. In the case of the Manuherikia River, because the nationally threatened Central Otago roundhead galaxias (CORG) has been for the most part extirpated by trout, we have focused on the flow requirements of the traditional mahinga kai species longfin eel[51] and key macroinvertebrates.

The flow regime identified to provide for longfin eel and macroinvertebrates is also assessed for its expected outcome for adult trout.

[50] For example, the presence of trout alters the drift behaviour of indigenous invertebrates, the presence and abundance of indigenous invertebrates as well as the presence and abundance on indigenous fish.

[51] Currently habitat is not limiting longfin eel in the Manuherikia catchment, eel are excluded from the catchment due to Roxburgh Dam with the exception of a few recruits from trap and transfer.

8.1.1. Proposed residual flow regime for Falls Dam

Currently there is a 0.5m^3/s residual flow below Falls Dam. As discussed earlier this reach was identified has an elevated risk for ecological values due to the existing flow regime (Section 7). As a result, a residual flow of 0.720 m^3/s has been proposed for Falls Dam[52] to address this risk. The habitat modelling suggests this would provide 80% or more habitat for both small and large longfin eels. This flow also provides >90% of habitat retention for upland bully. A residual flow of 0.720 m^3/s would provide >70% habitat retention for *Deleatidium*, >60% habitat retention for *Pycnocentrodes* and *Aoteapsyche*. *Deleatidium* is among the most abundant macroinvertebrate taxa present in the Manuherikia.

Under its existing state the Manuherikia River provides a regionally significant adult trout fishery and a residual flow of 0.720 m^3/s would provide ~60% habitat retention for adult trout in the Manuherikia relative to the natural 7-day MALF[53]. A flow of 0.720 m^3/s is significantly higher than the existing daily minimum of 0.5 m^3/s at Falls Dam[54]. This increase in residual flow would result in a 19 – 36 %[55] increase in habitat for trout compared to the status quo.

8.1.2. Proposed residual flow for the OAIC main race intake

Currently there is no residual flow below the OAIC intake and as discussed earlier this reach was identified as having an elevated risk for ecological values due to the existing flow regime (Section 7). Existing management can see flows as low as 0.3 m^3/s below this point for very short periods of time although this scenario only occurs when Falls Dam is not spilling and tributary inflows are sufficiently high to both meet demand from the downstream schemes and the 0.900 m^3/s target flow at Campground.[56]

In these circumstances as tributary flows recede, Falls Dam will start to release water to counter the reduction in tributary inflows to ensure that 0.9 m^3/s is maintained at the Campground flow site. Once this occurs the reach between OAIC's intake and the Dunstan Creek carries a good flow of water.

It is 4 km's from OAICs intake to the Dunstan Creek confluence. If Falls Dam was required to release more water during these infrequent events to provide more habitat in this relatively short reach (6% of the river length from Falls Dam to Clutha confluence) it would reduce the amount of stored water available to be released for the remainder of the irrigation season. Release of water throughout the season is needed to meet demand and counter lower tributary inflows along the greater length of the Manuherikia River, at least to Ophir (at least 60% of the river length from Falls Dam to Clutha confluence). Releasing too much too early for only a 4km reach would be detrimental to both ecological outcomes and abstractors.

To protect the ecological values between the OAIC intake and Dunstan Creek confluence we recommend a residual flow of 0.5 m^3/s past the OAIC intake. This is based on our understanding that flows at or about this residual flow will be infrequent and of a relatively short duration[57].

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[52] WRM Ltd and Freestone Freshwater Ltd. Nov 2020. Assessment of Environmental Effects of Falls Dam Hydrology & Aquatic Ecology.
[53] Wilding T2 curve
[54] 0.5 m^3/s is the current consented residual flow below Falls Dam.
[55] 19% based on Wilding T2 curve and 36% based on Jowett and Hayes curve.
[56] Pers Comms. Roger Williams Falls Dam and OAIC Race Operation Manager
[57] We expect this to be for days to weeks and not weeks to months.

A flow of 0.5 m^3/s below the OAIC intake will provide >70% habitat protection for large longfin eels and >90% habitat protection for upland bully and >60% habitat protection for *Deleatidium*.

For adult trout, a residual flow of 0.5 m^3/s below the OAIC intake represents more than a doubling of habitat for all age classes of trout relative to the status quo (Table 23).

9. Proposed Irrigation season (Oct – April) Minimum Flow at Campground Flow Site

It is clear from the longitudinal flow profiles presented in Figure 14 and Figure 15 that the key reach of river that would be protected from a minimum flow at Campground is from the MICS intake to the confluence. For the most part, upstream of the MICS intake is regulated by the location of the large scheme takes and releases from Falls Dam.

Downstream of the MICS intake flows historically can become low to the point of impacting on aquatic habitat for fish and macroinvertebrates. A minimum flow of 1.1 m^3/s is proposed at Campground flow site. Relative to natural MALF a flow of 1.1 m^3/s provides greater than 90% habitat protection for both large and small longfin eel and adult brown trout based on the Jowett and Hayes curve developed in New Zealand. 1.1 m^3/s also provides more than 80% habitat protection for juvenile trout relative to the natural 7-day MALF.

For the most common macroinvertebrate species in the lower Manuherikia *Deleatidium* and *Pycnocentrodes* a minimum flow of 1.1 m^3/s provides more than 70% habitat relative to the natural 7-day MALF. However, when considering invertebrate habitat it is commonly accepted that higher flows such as median flow are a better indicator of macroinvertebrate production[58], compared to consideration of fish habitat, which is typically done in reference to low flow statistics, such as the 7-d MALF. The habitat modelling completed at Galloway covers a flow range from 0 to 6 m^3/s while the observed median flow at the Campground flow site is ~12 m^3/s, which means it is not possible to fully assess the effects of flow alterations on invertebrate production using the available habitat model.

The pattern of water use in the Manuherikia means that the observed median flow statistic is less affected by taking than those towards the 7-day MALF (Figure 11), indicating that invertebrate production is unlikely to be adversely affected by existing abstraction. This is borne out by the SoE data at the Galloway site presented in Table 17 which shows an abundant macroinvertebrate community dominated by *Deleatidium* during all sampling occasions.

The habitat modelling at Galloway shows that as flows increase preferred conditions for long filamentous algae decrease (Figure 41). The habitat modelling also indicates that flows of about 1.1 m^3/s will only modestly increase the risk of the proliferation of long filamentous algae compared to naturalised flows (i.e. habitat quality at 1.150 m^3/s is ~150% of that at the naturalised 7-d MALF). This suggests that there is little benefit in increased minimum flows to reduce the prevalence of long filamentous algae within the modelled flow range (Figure 41). A minimum flow of 1.1 m^3/s would

[58] Page 112 of Hayes J, Hay J, Gabrielsson R, Goodwin E, Jellyman P, Booker D, Wilding T, Thompson M 2018. Review of the rationale for assessing fish flow requirements and setting ecological flow and allocation limits for them in New Zealand—with particular reference to trout. Prepared for NIWA, Envirolink, Greater Wellington Regional Council and Hawke's Bay Regional Council. Cawthron Report No. 3040. 150 p.

reduce the risk of the proliferation of long filamentous algae compared to existing low flows (based on Figure 41).

The reach from the MICS intake to the Chatto Creek confluence is likely to be less flow sensitive than the habitat modelling reach at Galloway given it is in a steep gorge and the river channel is much more confined. For this reason, we have not recommended a residual flow for the MICS intake and expect a minimum flow of 1.1 m^3/s at Campground to provide for ecological values below the take.

For the GIS take we have also concluded that a minimum flow at Campground of 1.1 m^3/s would ensure sufficient flow past the intake to provide for ecological values on the basis that bywashing to clear screens is kept to a minimum i.e. less than 0.1 m^3/s.

The Manuherikia water users as a group have committed to maintain the following flows throughout the Manuherikia River during the irrigation season:

1. 0.720 m^3/s residual flow at Falls Dam.
2. 0.5 m^3/s residual flow at OAIC's intake.
3. 0.250 m^3/s residual flow from Dunstan Creek
4. 0.1 m^3/s residual flow from Lauder Creek
5. 0.07 m^3/s residual flow from Thomsons Creek
6. 0.1 m^3/s residual flow from Chatto Creek.
7. 0.015 m^3/s residual flow the Lower Manorburn Dam
8. 0.820 m^3/s minimum flow at Ophir.
9. 1.1 m^3/s minimum flow at Campground.
10. Sharing regime to ration water to deliver each tributary residual flow and the two mainstem minimum flows.

In our analysis we have not recommended the Ida Valley Irrigation Company (IVIC) be subject to minimum flows in the Manuherikia as during times of low flow IVIC are operating on stored water[59].

Figure 42 and Figure 43 below provides longitudinal flow comparisons of the above regime during times of low flow relative to both natural and observed flows with the addition of a minimum flow of 1.1 m^3/s at Campground flows site.

When viewing Figure 42 and Figure 43 (and any longitudinal flow profile in this report) it is important to note that these are length of river profiles and that within reaches of alluvial rivers it is normal for there to be variation of flow as water moves in and out of gravel bars etc. which will mean there will be local scale variation around the flows presented but overall, we anticipate the flow patterns presented demonstrate the relative differences between scenarios discussed.

[59] Refer to the IVIC application AEE.

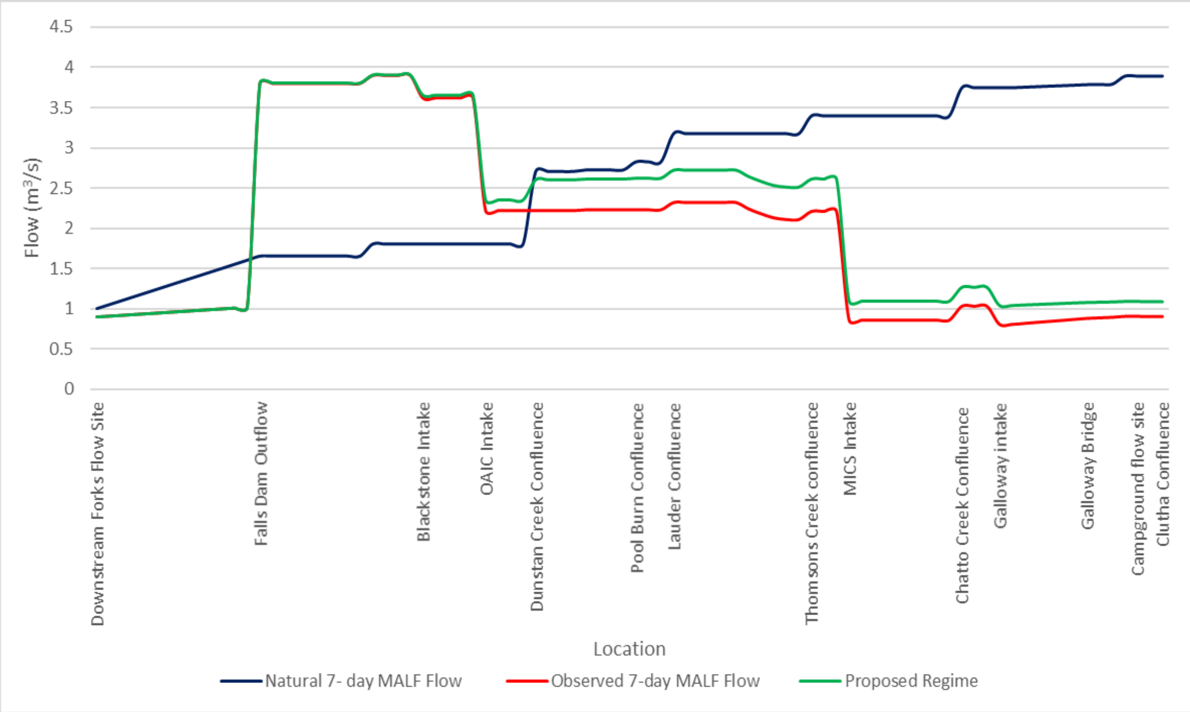

Figure 42. Comparison of longitudinal flows at the natural 7-day MALF (3.9 m^3/s) to the observed 7-day MALF (0.911 m^3/s) and flows expected implementing residual flows at key locations in the catchment with a minimum flow of 1.1 m^3/s at Campground flow site. It is 83 kms from the Forks Flow Site to the Clutha Confluence.

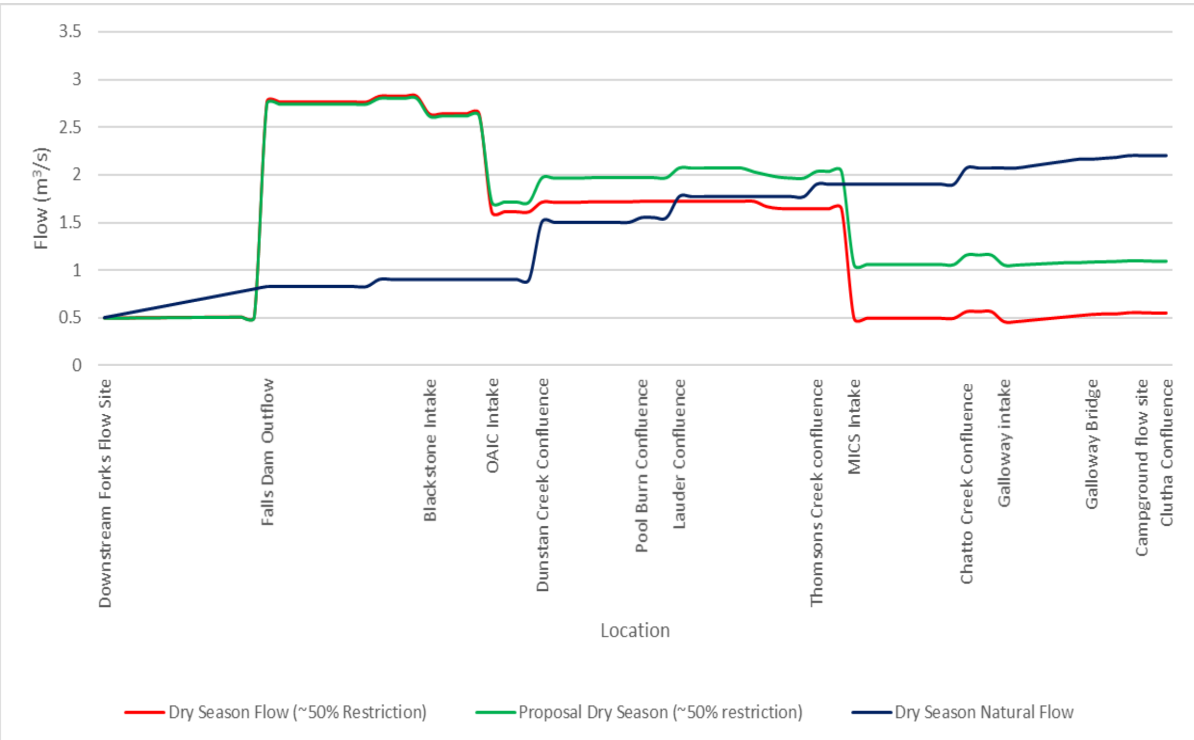

Figure 43. Comparison of longitudinal flows at a natural low flow comparable to January 2018 (2.125 m^3/s) to the observed low flow (0.660 m^3/s) and flows expected implementing residual flows at key locations in the catchment with a minimum flow of 1.1 m^3/s at Campground flow site. It is 83 kms from the Forks Flow Site to the Clutha Confluence.

In recommending a minimum flow of 1.1 m^3/s at Campground we are aware that a hydrological model is being built as part of ORC's Manuherikia environmental flow setting process, unfortunately at the time of lodging consent this model was not available. As discussed below in Section 10 we are of the view that when setting the minimum flow at Campground strong consideration should be given to the consequences on Falls Dam storage. Our recommendation of 1.1 m^3/s at Campground is on the premise that it does not inadvertently lead to depleted flows from Falls Dam to the Clutha confluence. If when the Manuherikia model is completed it shows significant periods when Falls Dam is empty or restricted, then it may be necessary to revisit the above minimum flow recommendation.

10. Consequences of Falls Dam running out to uphold the river flows

In considering minimum flow options at Campground flow site, it is easy to think that an increase in minimum flow can be easily accommodated by releasing more water from storage to meet the shortfall in flows created by abstraction demand. However, Falls Dam is a relatively small storage facility and that modest increases in minimum flow have significant consequences on the rate that storage is depleted, particularly in dry seasons.

As explained earlier, during times of low, flow Falls Dam releases are managed to provide for taking while aiming to maintain 0.9 m^3/s at the Campground flow site, and as inflows between the dam and Campground recede, releases from Falls Dam increase. This is a different approach to letting the river recede and then simply releasing the stored water for taking without consideration of flow left in the river.

Because of the way Falls Dam is managed with respect to trying to maintain a flow at the Campground flow site the Manuherikia Catchment Group (MCG) have previously investigated the impact of increasing minimum flows at the Campground flow site on irrigation demand and Falls Dam storage based on existing use and tributary inflows[60]. This report found that in dry seasons such as 2014/15 a minimum flow of 1.250 m^3/s would severely impact on storage and that a minimum flow of 2.5 m^3/s would cause Falls Dam to empty in many seasons including "wet" years.

Once Falls Dam is empty, outflows will only match inflows to the dam. Emptying the dam in January or early February to maintain a higher minimum flow at the Campground flow site would mean river flows above the MICS intake would be lower for more of the irrigation season. This is because once storage is exhausted the positive effects of using the river to deliver water to downstream users is lost.

Figure 44 below provides a comparison between Falls Dam being empty with inflows of close to the observed 7-day MALF (average low flow conditions) to the dam operating at a "normal" outflow and a "restriction" outflow. In the three scenarios the flows entering the Manuherikia from tributaries have been assumed to be:

- Dunstan Creek 0.250 m^3/s
- Becks Creek 0.01 m^3/s

[60] WRM Ltd. 2017. Assessment of the implications for Falls Dam storage with minimum flow options ranging from 1.25 – 2.5 m^3/s at Campground flow site on the Manuherikia River for the 14/15, 15/16 and 16/17 irrigation seasons.

- Pool Burn 0.01 m^3/s
- Lauder Creek 0.1 m^3/s
- Thomsons Creek 0.7 m^3/s
- Chatto Creek 0.1 m^3/s
- Manor Burn 0.015 m^3/s

For the dam empty scenario, the minimum flow at Campground is 1.5 m^3/s while for the two other scenarios it is 1.1 m^3/s. The total tributary take for each scenario is the same while the mainstem take in each scenario is provided in Table 36.

Table 36. Mainstem take under the three different scenarios presented in Figure 44.

Scenario	Mainstem Take (m^3/s)
Dam Empty – Higher minimum flow at Campground	0.130
Proposed regime – Normal operation	3.399
Proposed regime – Under restriction	1.404

The key understanding from Figure 44 below is that as long as Falls Dam is releasing water for downstream irrigation use and a reasonable minimum flow is set at Campground the outcome for the ecological values along all of the river is better than if Falls Dam is on restrictions or empty due to a higher minimum flow being in place at Campground. Also, of note from the comparisons in Figure 44 is the impact on available water for taking for mainstem takes when demand for water would be high (Table 36).

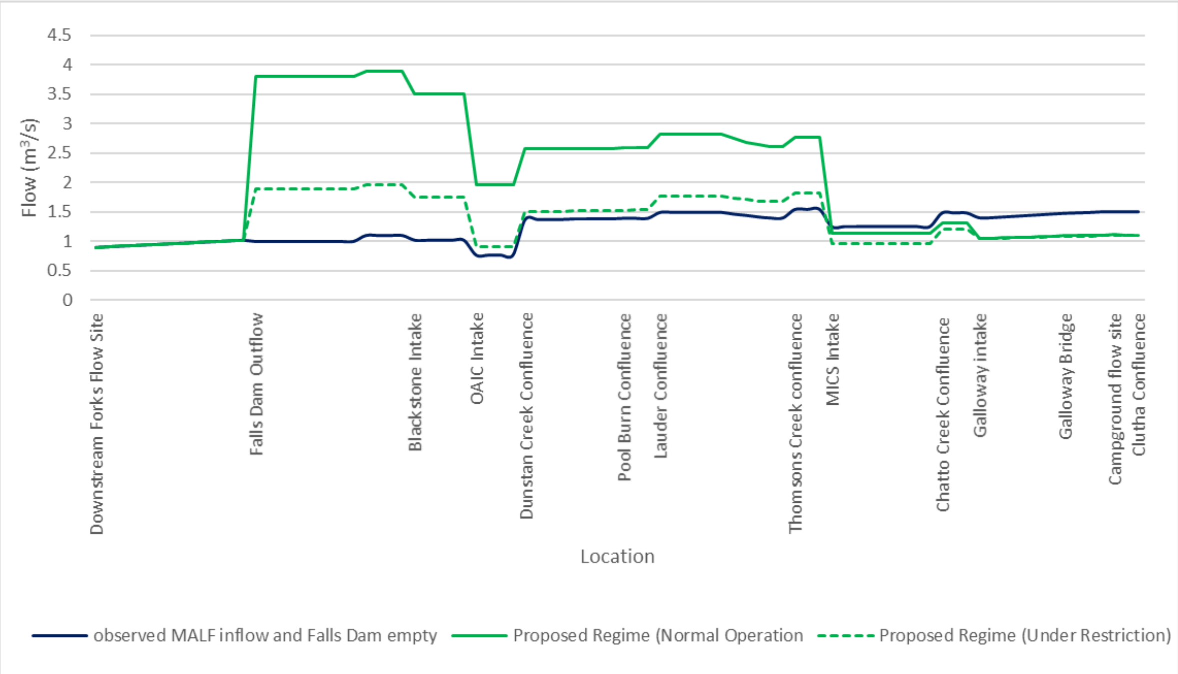

Figure 44. provides a comparison of the Longitudinal flow profile comparing outflows from Falls Dam matching inflows of close to observed MALF with a minimum flow at Campground of 1.6 m^3/s to flows expected under different outflow scenarios depending on dam levels and restrictions and a minimum flow of 1.1 m^3/s at Campground. It is 83 Km's from the Forks Flow Site to the Clutha Confluence.

The longitudinal flow profiles in conjunction with the habitat modelling results throughout the mainstem suggest that retaining higher flows from Falls Dam to the MICS intake for as long as possible is more beneficial ecologically than solely retaining a higher minimum flow in the lower river until storage is exhausted and river flows collapse.

Within reason,[61] this suggests managing Falls Dam to retain as much storage as possible for as long as possible into the irrigation season should be a fundamental consideration of any minimum flow placed on the lower Manuherikia River.

11. Proposed Winter (May-Sept) Minimum Flow at Ophir and Campground Flow Sites

The proposed residual flow conditions will result in reduced surety of supply or access to water by permit holders during the irrigation season. This is anticipated to result in a greater focus on accessing water for on-farm storage. As a result of this potential shift in accessing water it is important to have winter flow controls on takes. This will address the potential effects of increased taking of water during winter of water.

As a group the Manuherikia water users have committed to maintain the following residual and minimum flows throughout the Manuherikia catchment for primary takes during winter (May – September):

1. 0.720 m^3/s residual flow at Falls Dam
2. 0.5 m^3/s residual flow at OAIC's intake
3. 1.0 m^3/s residual flow from Dunstan Creek
4. 0.360 m^3/s residual flow from Lauder Creek
5. 0.180 m^3/s residual flow from Thomsons Creek
6. 0.250 m^3/s residual flow from Chatto Creek
7. 3.2 m^3/s minimum flow at Ophir
8. 0.05 m^3/s residual flow from Manor Burn
9. 4.0 m^3/s minimum flow at Campground

12. Supplementary minimum flow at Ophir and Campground flow sites

With increases in utilising storage many water users wish to be able to fill that storage as quickly as possible when flows allow, therefore it is anticipated that there will be an increased demand for supplementary taking in the Manuherikia.

[61] By this we mean we would not suggest an extremely low minimum flow (<0.5 m^3/s) at Campground for the purpose of protecting storage.

There is no formula for setting supplementary minimum flows and our preferred approach is to consider particular ecological values that require higher flows to occur. Traditionally this is for things such as adult trout habitat, trout spawning or fish migration.

The habitat analysis for the lower river shows that flows that provide optimum habitat for spawning are very low at 1.2 m^3/s, while optimum flow for adult trout habitat is 2.2 m^3/s.

The analysis by Ryder (2020) has shown that a flow of >3.3 m^3/s would be needed provide passage throughout the lower Manuherikia River (Chatto Creek to Clutha Confluence) for adult trout. The Ryder (2020) analysis found that a flow of 3.3 m^3/s at Campground flow site easily provided water depths of 0.2m greater than 1m wide at Galloway Bridge and Olrig Station but not at Fisher lane. A flow of 3.3 m^3/s at Campground resulted in 0.15m depths at Fisher lane (Ryder 2020).

Fish and Game Otago also carried out a passage analysis in the lower Manuherikia and that indicated a flow of ~2.5 m^3/s would provide passage for adult trout at the riffles they surveyed[62].

Based on the above assessment of passage requirements we recommend a supplementary flow of 6 m^3/s all year to provide for adult trout passage which will also ensure passage for all indigenous species present in the lower Manuherikia mainstem[63]. Our recommendation would be to allocate supplementary allocation in 0.5m^3/s blocks and that existing supplementary takes should be in the first supplementary block of allocation[64].

12.1. Fish Passage - Structures

The four main scheme intakes have been assessed for potential issues with fish passage, where there is a structure in the river, we have provided more detail on passage.

Blackstone Irrigation Company have no structure in stream other than a gravel bund that guides flow to their intake. There is free passage past the intake.

[62] Otago Fish and Game Council. Fish and Game Values in the Manuherikia River Catchment. Updated January 2020

[63] All indigenous fish comfortably pass riffles at the depths that large trout require.

[64] We acknowledge this would require a variation of existing consent conditions.

Figure 45. Blackstone irrigation Company intake.

Omakau Area Irrigation Company main race intake weir is concrete with a rounded crest shape and is 60 m wide. At the time of survey, the flow was ~4.0 m^3/s the width of surface water across the weir was 29m and the weir height was 2.6 m in two drops of 1.2 and 1.4 m's respectively (Figure 46 to Figure 48).

Figure 46. Aerial Photograph of the OAIC main race intake on the Manuherikia River.

Figure 47. Photograph of the OAIC main race intake on the Manuherikia River looking upstream.

Figure 48. Photograph of the OAIC main race intake on the Manuherikia River from the True Left bank.

This structure is likely to be partial barrier to trout, with large adult trout potentially able to make passage at high flows. Anecdotally, large trout have been seen attempting passage. Non-migratory galaxiids and upland bullies are not expected to be able to make upstream passage past this weir. Due to their strong climbing abilities, longfin eels, lamprey and kōaro are expected to be able to make passage past this weir (Olsen 2020).

Brown trout, rainbow trout and upland bully are abundant upstream of OAIC's main race intake, indicating a self-sustaining population above it. Longfin eel and lamprey are rare in the Manuherikia (compared to natural state) due to the Roxburgh Dam. Finally, there are few kōaro in the Manuherikia catchment, probably as a result of damming and trout predation.

Manuherikia Irrigation Company Society has a large broken rock bund that guides flow towards their intake. There are no large vertical drops at the intake and water flows through and between the rocks. On inspection at very low flows (0.693 m^3/s daily average flow at Campground) passage for fish was not considered an issue (Figure 49).

Figure 49. Manuherikia Scheme intake 11th February 2019. Daily average flow at Campground 0.693 m^3/s.

Galloway irrigation Company has a gravel wing wall that guides flows towards their intake. Some flow is bywashed back to the river some 1.5 km's below the intake which allows the fish screen to operate effectively.

Figure 50. GIS intake with a flow of approximately 1.6 m^3/s Campground.

Figure 51. Photo taken during ORC site visit on the 9th Dec 2020 - Flow at Campground approximately 0.96 m^3/s.

We expect that with a minimum flow of 1.1 m^3/s at Campground, and active management to minimise by-washing, that passage will be provided past the GIS intake. It is noted that GIS have a fish screen installed at their pump station that a requires minimum amount of bywash to keep the screen clear and for fish to access back to the river in the bywash channel.

Figure 52. Intake and Screen at the GIS pumps.

13. Fish screening

Fish screens are typically installed to prevent fish from being entrained into water take infrastructure (e.g. race, pipe) and to return the fish unharmed to the waterway they came from. The design parameters for fish screens vary depending on the setting and the species/life-stage of fish present. In general, screens will be designed to comply with fish screening standards and guidelines (as outlined in Schedule 2 of the Canterbury Land and Water Regional Plan). An example of a condition that has been developed to comply with these guidelines is provided below:

(a) The site is located as close to the river source as possible to minimise exposure of fish to the fish screen structure, and minimises the length of stream affected while providing the best possible conditions for (b) - (f) below;
(b) Water velocity through the screen ("approach velocity") is slow enough (generally <0.12 m/s) to allow fish to escape entrainment (being sucked through or washed over the screen) or impingement (being squashed or rubbed against the screen);
(c) Water velocity across (or past) the screen ("sweep velocity") is greater than the approach velocity (b) and is sufficient to sweep the fish past the intake;
(d) An effective bypass system is provided that is easily accessible to entrained fish, and fish are taken away from the intake and back into the source channel, or into water which provides the fish with unimpeded passage back into the source channel;
(e) Screening material (mesh, profile bars or other) on the screen needs to have a smooth surface and openings that prevent any damage to fish from coming into contact with the screening material; and
(f) The intake structure and fish screen are operated to a consistent, appropriate standard with appropriate operation and maintenance procedures, and this operation and maintenance

should be regularly checked or monitored. A record should be kept of all the maintenance and monitoring carried out.

Given the species present in the Manuherikia mainstem our recommendation would be for 3mm mesh for any fish screens to be installed. Based on the age and location of some of these existing intakes we expect there will be significant challenges with installing fish screens particularly within the context of the flow range and conditions that they will need to withstand. It is likely that investigations as to practicable options will be necessary to achieve the desired outcomes.

14. Summary

The Manuherikia River has a high degree of hydrological alteration due to the effects of water storage, augmentation and abstraction. We have shown that the reaches of river with the greatest departure from its natural flow pattern at times of low flow is from Falls Dam to the OAIC intake (augmented) and the MICS intake to the Clutha confluence (reduced) (Figure 14).

Our analysis has also shown that the dam and abstraction has little (if any) effect on flows above median flow at the Campground flow site and therefore abstraction is unlikely to affect periphyton flushing[65] in the lower Manuherikia. Accrual analysis based on observed flows at the Campground flow site indicates when a flushing flow does occur following rain it results in a mean flush flow of more than 80 m^3/s during the irrigation season.

The Manuherikia River between Falls Dam and Ophir only has records of one species of indigenous fish, upland bully. While from Ophir to the Clutha confluence upland bully and Longfin eel have been recorded more than a few times[66]. Upland bully are common and widespread while longfin eel are uncommon despite significant physical habitat for this species throughout the catchment. The Central Otago roundhead galaxias would naturally have been expected to inhabit the Manuherikia mainstem but has been extirpated by introduced trout.

Habitat modelling by NIWA and Waterways Consulting on behalf of ORC shows that a flow of 0.658 m^3/s provides more than 80% of habitat retention relative to the natural 7-day MALF for large longfin eel at all mainstem habitat modelling sites (see Table 21, Table 26 and Table 31).

The habitat modelling results support the position that the scarcity of longfin eel in the Manuherikia catchment is due to a lack of recruitment past Roxburgh Dam and commercial harvest and not due to a lack of habitat due to low flows under the existing flow regime. In order to return longfin eel in numbers that would meet the NPSFM (2020) compulsory value for mahinga kai or return stocks to any semblance of what would have been present under a natural state will require a dedicated effort over many decades to transfer elvers past the Roxburgh Dam.

Under the existing flow regime, the mainstem of the Manuherikia is a regionally significant trout fishery with over 2,140 ± 830 angler days in the 2014/15 season[67]. The level of fishing effort puts the Manuherikia River under its existing flow regime in the top 50 most fished rivers in New Zealand[68]. Further to this two still water fisheries the Poolburn and Manorburn Reservoirs are also considered

[65] We have used flows of 3x median flow or greater as periphyton flushing flows.
[66] Lamprey, Central Otago Roundhead galaxias and koaro have been recorded on rare occasions.
[67] Unwin, 2016. The national angler survey.
[68] Paragreen. N (2020). Presentation on behalf of Otago Fish and Game to the Manuherikia Reference Group.

regionally significant trout fisheries by Otago Fish and Game[69] and would not exist under natural state conditions as these are storage reservoirs built specifically for irrigation.

Habitat modelling by NIWA and Waterways Consulting on behalf of ORC has shown that although naturally flows would increase from Falls Dam to the Clutha confluence (Figure 14), the flows that offer optimum habitat for adult trout at each of the modelled reaches decrease with distance downstream of Blackstone Hill (see Table 22, Table 27 Table 32).

We have also presented the risk to flows along the Manuherikia River if Falls Dam is emptied. This has shown that maintaining irrigation releases from Falls Dam is more beneficial for aquatic habitat over the whole river length than retaining a higher minimum flow in the lower river. With increasing minimum flow levels in the lower river, the risk of exhausting Falls Dam storage increases and the subsequent ecological risk across the river length increases also.

The longitudinal pattern of flow and habitat requirements suggests that the adult trout fishery in the Manuherikia River benefits significantly from releases from Falls Dam and that without Falls Dam releasing flow for downstream taking adult trout habitat upstream of Ophir would be reduced.

Increasing the draw on Falls Dam as a result of a higher minimum flow at Campground would result in significant variation in water levels in the dam compared to what occurs under the existing management regime. We would anticipate that this would degrade the productivity of the Falls Dam trout fishery, which in turn may also impact the backcountry trout fishery upstream of Falls Dam.

Water quality for the most part along the mainstem of the Manuherikia is good, meeting ORC's Schedule 15 water quality limits for nutrients at most sites throughout the river, with the only exception being DRP. Compared to the NOF nutrient concentrations are in the A band for ammoniacal N and NNN while DRP is C band at sites from Ophir downstream. The most recent trend analysis by NIWA[70] indicates that DRP concentrations are reducing which likely reflects the recent upgrades from overland irrigation to spray in the catchment over the last few years in anticipation of the water use efficiency requirements in the Regional Plan: Water and the NPSFM (2020) and its previous iterations.

The influence of overland irrigation and point source discharges are evident as elevated DRP, turbidity and *E. coli* levels at times from Ophir downstream. Converting overland flow irrigation methods to spray is expected to reduce contaminants entering waterways, along with an increase in residual flows being left in tributary streams is expected to see improvements in water quality. Other initiatives such as stock exclusion from streams as required by the NPSFM (2020) will also reduce these contaminants.

At times of normal to low flow (< than median flow) microbial contamination is generally low in the Manuherikia River, meeting the Schedule 15 limit at all mainstem SoE sites except Ophir. The Ophir water quality site is immediately downstream of both Thomsons Creek[71] and the Omakau wastewater discharge. At the time of writing this report there is significant work occurring or about to occur in Thomsons Creek to address water quality concerns. This includes a recent funding grant from the Ministry for the Environment to construct a wetland to reduce nutrient losses. There have also been recent upgrades to the Omakau township wastewater discharge which are expected to see improvements to *E. coli* loads to the Manuherikia River.

[69] Section 5.2 of SPORTS FISH AND GAME MANAGEMENT PLAN FOR OTAGO FISH AND GAME REGION 2015-2025.
[70] See Table 8 of this report.
[71] Thomsons Creek has high *E.coli* levels based on SoE monitoring at SH85.

Throughout the catchment at times when people are reasonably expected to be recreating in the Manuherikia River[72] risk of illness from primary contact recreation in the Manuherikia is low. Our expectation is that with the recent upgrade of the Omakau wastewater discharge and anticipated changes to efficient spray irrigation that this risk will reduce further. Our examination of the bacterial data in conjunction with our knowledge of the catchment would lead us to encourage the ORC to undertake targeted faecal source tracking[73] to better target further reductions in *E. coli* in the Manuherikia.

Monthly monitoring of periphyton cover and biomass at Blackstone Bridge, Ophir and Galloway shows the invasive diatom Didymo dominated cover at Blackstone Hill on most occasions and that the biomass of periphyton was generally low to moderate at the Blackstone Hill site. The periphyton community at the Ophir and Galloway monitoring sites was generally dominated by thin light brown films (likely dominated by diatoms), although filamentous algae dominated both sites on occasion.

Interestingly SoE monitoring is showing Didymo is less abundant at sites downstream of Ophir despite its prevalence upstream, one reason may be that Didymo is known to be sensitive to elevated levels of DRP[74]. This does raise the issue that reductions in DRP concentrations towards the rivers natural state may see the unintended consequence of Didymo dominating periphytons communities below Ophir given its prevalence upstream.

Overall using the NOF trophic state attribute as measured by chlorophyll-*a* biomass based on a monthly monitoring regime and acknowledging that there is not at least 3 years of data the sampling results so far indicate that all three sites mainstem sites in the Manuherikia are in the B-band for biomass.

Macroinvertebrate monitoring throughout the river under the existing flow regimes shows that depending on the metric used the sites monitored in the mainstem downstream of Falls Dam are classified from A to C Band under the NOF. Interestingly some of the lower MCI scores occur where water quality is known to be good which indicates that the invasive pest didymo is impacting some sites, particularly in the upper river at Loop Road and Blackstone.

Macroinvertebrate monitoring between Falls Dam and the Clutha confluence shows that the macroinvertebrate community in the reach of river with the greatest departure from natural flows (Galloway) is comparable if not better than any other monitoring sites upstream with less altered flows. Our analysis suggests that by implementing a minimum flow of 1.1 m^3/s that there will be an increase in macroinvertebrate habitat in the lower river during times of low flow compared to existing flows.

Fish passage has been assessed for all the large scheme intakes with none of the intakes expected to provide issues for migratory indigenous species. The OAIC intake weir likely impedes upstream trout passage but there is a self-sustaining population of large brown and rainbow trout upstream indicating passage is not causing significant issues. While an assessment of fish passage in the lower Manuherikia

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[72] Primary contact recreation is expected to occur when flows are less than 10 m^3/s and temperatures are greater than 15^0C

[73] Faecal source tracking can be used to determine whether the source is agricultural, avarian or human for example. Each source would require different interventions.

[74]Bothwell, M.L., Brad, M.L., Taylor, W. & Kilroy, C. (2014): The Didymo story: the role of low dissolved phosphorus in the formation of Didymosphenia geminata blooms, Diatom Research, DOI: 10.1080/0269249X.2014.889041

has also found that flows of 0.7 m^3/s or more at Campground flow site provided passage at critical riffles for indigenous fish.

A supplementary minimum flow at Campground of 6 m^3/s has been recommended. This flow is higher than the natural 7-day MALF and is expected to conservatively provide unimpeded passage for adult trout throughout the lower Manuherikia (Chatto Creek to Clutha confluence). As adult trout have the highest passage requirements all other species and life stages will also have unimpeded passage.

Fish screens are recommended for all takes from the mainstem; our expectation is that given the species present 3mm mesh screens would be adequate. However, we would also suggest that sites for screening are best investigated on a case by case basis given the significant existing infrastructure already present.

It is expected that the combination interventions outlined in this report and summarised in Table 37 along with changes to more efficient irrigation methods[75] and increased stock exclusion[76] will ensure that water quality and ecological values of the Manuherikia River are maintained or improved.

[75] Shifting from overland to spray irrigation.
[76] As required by the NPSFM (2020).

Table 37. Summary table of key mitigation measures to proposed to manage the ecological effects of abstraction along the mainstem of the Manuherikia River.

Site	Residual flow	Fish screening	Minimum flow at Ophir	Minimum flow at Campground	Water sharing Recommended
Falls Dam	0.720 m^3/s below dam	Not recommended	N/A	N/A	N/A
BIC Intake	Not required	Yes – 3mm mesh	Yes 0.820 m^3/s	Yes – 1.1 m^3/s	yes
OAIC intake	0.5 m^3/s below take	Yes – 3mm mesh	Yes 0.820 m^3/s	Yes – 1.1 m^3/s	yes
Private irrigation takes[77] upstream Ophir	Not required	Yes – 3mm mesh	Yes 0.820 m^3/s	Yes – 1.1 m^3/s	yes
MICS intake	Not required	Yes – 3mm mesh	No	Yes – 1.1 m^3/s	Yes
GIS intake	Not required[78]	Yes – 3mm mesh	No	Yes – 1.1 m^3/s	yes
Private takes downstream Ophir	Not required	Yes – 3mm mesh	No	Yes – 1.1 m^3/s	yes[79]

[77] Omakau town supply is in this reach.

[78] On the basis that the new intake design minimises bywash thereby leaving the majority of flow passing the point of take instream.

[79] These takes are very small (combined less than 10 l/s) and one take is below the Campground Flow Site. Excluding these from sharing will make little difference to flows

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Appendix 1– What triggers a restriction in the Manuherikia Catchment water takes and Falls Dam release.

By Roger Williams, Omakau Irrigation Company Operations Manager

August 2017

Falls Dam has entered into an agreement with the water users in the catchment to work together to restrict water takes to the same level when restrictions are called by Falls Dam Company.

Water is released from Falls Dam during the irrigation season to maintain irrigation levels and the regulatory and voluntary minimum flows at Ophir and Campground.

Falls Dam is a modest storage facility of approximately 11 Mm^3, much smaller than some other water storage dams in Central Otago. Rather than simply storing winter water, it is also reliant on summer rains in the mountains to replenish it during the irrigation season.

The trigger for a restriction is largely based on the days of storage remaining in Falls Dam. The decision to restrict also depends the time of year. We restrict earlier if we are facing a water shortage earlier in the season. Consideration is also given to the likelihood of further summer rains in the mountains and whether Falls Dam will get a recharge.

Restrictions have been 80%, 75%, 50%, 25%, 20% and can be any combination.

For example, example if we hit 30 days storage left in early January we would likely go to 50% restriction immediately but if we hit 30 days storage at the start of March we might go to 75% restriction.

There is usually around 30 days of storage remaining when a restriction is called. This storage figure is calculated daily.

The two main contributing factors influencing the storage level are the inflow to the dam and the outflow from the dam. The weather has a major influence on the inflow and the outflow requirement. Consequently, the figure for days remaining fluctuates.

A hot windy day can see a major reduction in creeks flowing into the Manuherikia and necessitate an increased outflow from Falls Dam. It can exceed 0.5 m^3 in a day. A rain event has the opposite effect.

The job of river management is to maintain enough water for some level of irrigation for as long as possible while also maintaining the minimum flows.

As operations manager, I check flow figures about nine times a day, seven days a week, always with a close eye on what is happening in the various tributaries, particularly Dunstan Creek.

Flow metering inaccuracies pose a significant challenge. I liaise with ORC staff regarding significant inaccuracies when I detect them.

It takes 26 hours for water released from Falls Dam to arrive at Campground.

There are a lot of variable factors influencing the flow at Campground.